Advanced Aircraft Seat Design
The Webbing Concept

by

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ABSTRACT

Air travel is so common in this day and age that any significant improvement in seat comfort on board a commercial passenger jet is likely to affect almost everybody. A proposed design concept in this project is the use of webbing as the substitute for current foam cushioning in the seat back. The result is a webbing-foam hybrid cushioning design that utilizes the benefits of both cushioning types to maximum effect. Experimental tests suggest that this design would also provide better overall comfort for the passenger. As a result, both consumer and industry would profit immensely from the implementation of such a design.

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    - Mr. Gettys Knox of Miliken and Co.
    - Mr. Nigel Robertson of Open Ergonomics

- My family whom I hold so dear, for always being there for me

And most of all, the Almighty Lord Jesus Christ without whom nothing is possible.

Chapter 1 – Introduction

1.1 Foundation

In the civil aviation industry, the tourist/coach/economy-class seat is the most common one found in passenger aircraft such as the Boeing 737 or the MD 80. The aircraft passenger seat is probably the most prevalent interface between the passenger and the aircraft. When a passenger is seated, the sense of well-being he feels while he is on the seat is defined as comfort.

1.2 Objective

The objective of this project is stated thus:

> *To find scientific, creative and innovative means to improve passenger comfort in tourist-class seats during long-haul flights.*

It is believed that improved passenger comfort during flights serves the interests of both the passenger and the airline. This is because a comfortable passenger is probably also a satisfied one (provided he receives decent service), and a satisfied customer will go back to the airline for more business, leading to increased revenue for the airline. Furthermore, this project is aimed at advancing the aircraft seat industry, resulting in seats of a significantly higher quality. Finally, it is hoped that the project would provide a greater competitive edge for airlines, aircraft makers and seat manufacturers alike, because they are the ones who will decide whether or not the new design is worth introducing to the market and will make an impact.

In the course of this project, a prototype was built and tested for the level of comfort that it provides to the passenger.

1.3 Defining The Problem

During long-haul flights lasting anything from three hours up to twenty, a passenger usually feels discomfort as the flight wears on. Aches in the back, neck and other parts of the body often accompany the passenger out of the plane at the end of a flight. As a result, one wonders whether current seats in civil aircraft can be improved to maintain passenger comfort at a decent level throughout the long air journey, so that passengers can come out of a prolonged flight without the physical after-effects.

Yet of course, a good seat does not just serve the one who uses it, but also the one who owns it. More often than not, seats of today are optimized to provide not just enough passenger comfort but also maximum revenue for the airline at the same time. There are many aspects of the seat in which one can see conflict of interest between the customer and the airline, such as:

- Personal Space - While the fact that more seating space makes a happier passenger goes without saying, airlines are hard pressed to maximize the number of passengers each plane can carry, thereby maximizing profit per flight.
- Seat Features – Passengers want more seat features and comfort, which the airline has to spend money to bring about.
- Cost - The customer wants to minimize the amount he has to pay for the ticket, whilst the airline wants to maximize profit.

Airlines must find the right combination of both parties' interests - to be able to make passengers happy enough to patronize them again, while at the same time generating the maximum revenue out of each plane in their inventory. But of course, both the passenger and airline do have some common interests:

- Passenger Comfort –All things being equal, increasing this would result in greater customer satisfaction and, in turn, airline loyalty, meaning more customers and increased revenue for the airline.

This project has the task of improving the above common interest of both airline and passenger and seeking a compromise between conflicting interests to come up with a seat design that finds the right balance in benefiting both parties.

1.4 The Design-Development Process

Having stated the objectives of this project, the team sought to identify and further analyze the requirements that such a design would exact. This was done by means of a customer survey and, following that, a Quality Function Deployment (QFD). These exercises defined the technical and customer requirements that would be needed for the team to come up with a satisfactory design.

With the requirements in mind, the team was better able to do a more focused research, in that each member would know what he or she was looking for when consulting various sources.

This enabled a greater degree of efficiency so that precious time is not wasted on unearthing information that would not prove vital or perhaps even necessary in the long run. During the research phase, the team also found ideas for design concepts, by conducting patent searches and checking out what is already out there in other fields, for example in the office chair market.

The Design-Development Process

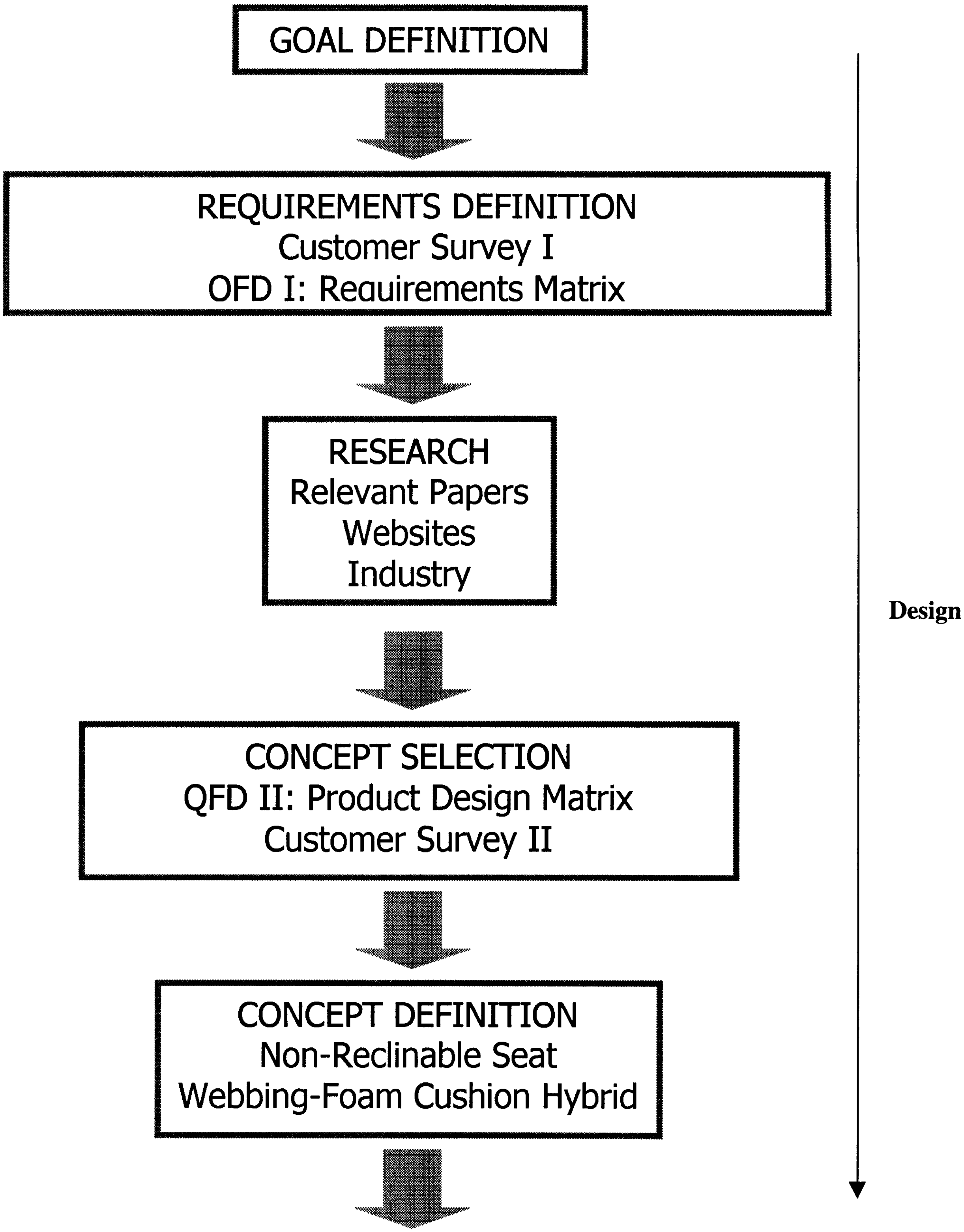

Figure 1.1: Design-Development Process

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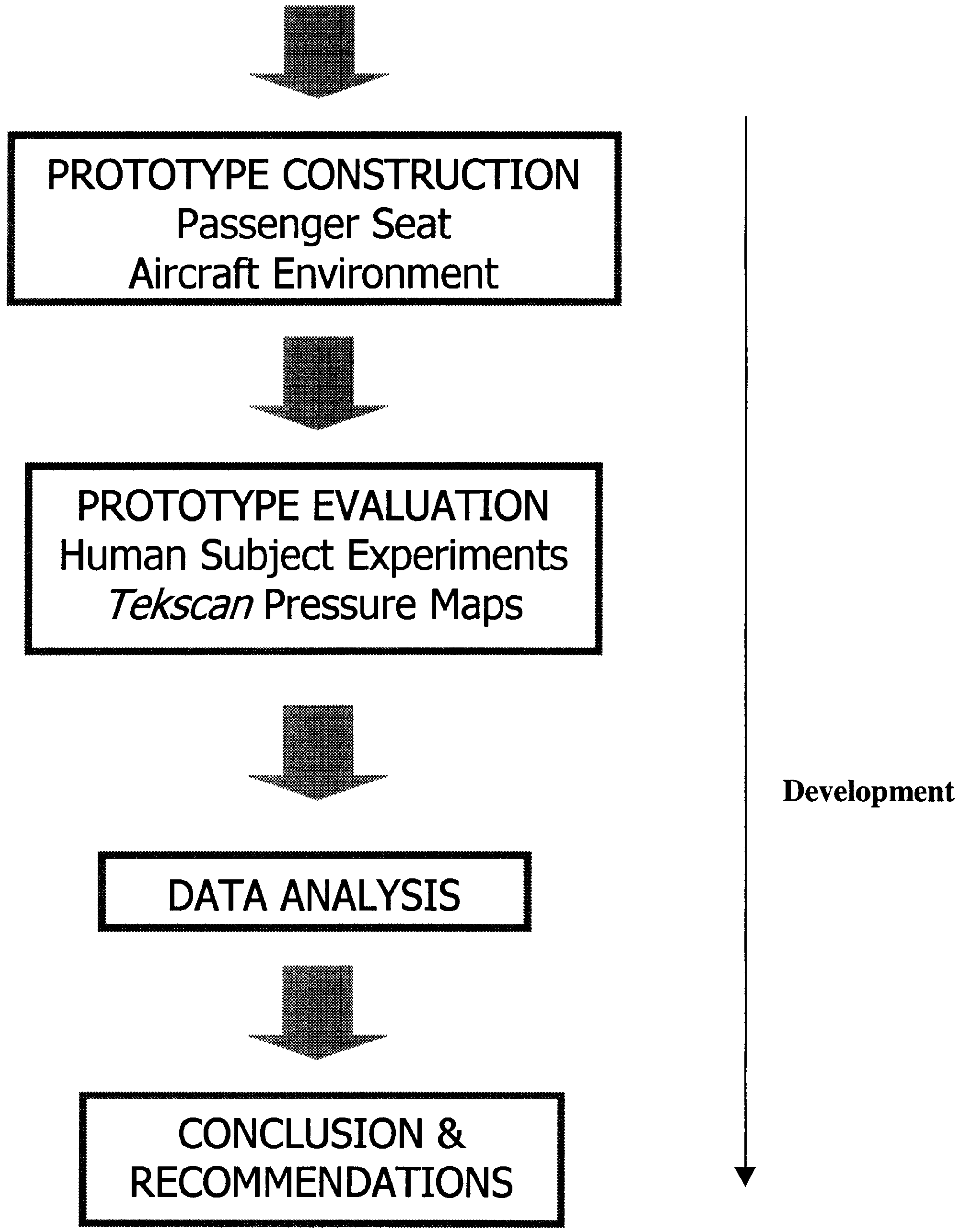

Figure 1.1: Design Development Process (cont'd)

After the research phase, the team gained sufficient knowledge to make discerning decisions where the design concept is concerned. This knowledge was augmented by findings from a second customer survey and a product design matrix. From there, the team came up with two design concepts: the Non-Reclinable Seat and the Webbing-Foam Cushioning Hybrid.

The period following concept definition was one of intense construction. Besides building the prototypes for testing – which was essentially modifying existing seats generously provided by BE Aerospace, the team also had to erect a structure to simulate passenger environment in a typical flight. These two aspects made up the testing conditions that were required for subjects to sufficiently evaluate the seat. Testing was of a comparative nature – subjects were asked to compare the two new concepts with an unchanged baseline seat that came right out of the BE Aerospace factories. Pressure-measurement pads purchased from Tekscan were also used to provide a more objective dimension to the testing process.

With the data obtained from the testing procedure, the team was able to analyze the comparative merits of the seats over the baseline, based on subject opinion and pressure data. From there, the team could make conclusions on the success of the seat prototypes as well as recommendations on what would be a more comfortable yet feasible design concept for an advanced aircraft passenger seat.

Chapter 2 - Requirements Analysis

Having identified and furthermore analyzed the problem at hand, the team turned its attention to the requirements of the advanced aircraft passenger seat. These requirements set the bearing for the design concept. Gathering the appropriate requirements for the design concepts was not a one-step process – the entire procedure consisted of a Functional Flow Diagram, a pair of Customer Surveys, two Quality Function Deployment matrices and numerous sessions of brainstorming and iteration. But at the end of the requirements analysis process, the team had a set of guidelines, so to speak, to work with in order to come up the optimum design concept for the aircraft passenger seat.

2.1 The Functional Flow Diagram

In order to track seat functions throughout the course of a flight, the team had to model the activities the passenger performs in the flight from start to finish. In this case, some sort of Functional Analysis had to be done – a systematic approach was required to translate system operational and support requirements into specific qualitative and quantitative design requirements. For example, if the aircraft seat is required to accommodate the sizes of the 5th percentile of human size to the 95th percentile, then an adjustable headrest would be designed to fulfill that purpose by having the necessary range of adjustment in order to fit this spectrum of human attributes.

A useful tool in the process of Functional Analysis is the Functional Flow Diagram (FFD). A highly useful tool for idea generation and visualization, it is defined as a pictorial scheme used as a mechanism for portraying system requirements, illustrating series and parallel relationships, and establishing a hierarchy of system functions. To put it simply, a flow diagram of functions that, in this case, an aircraft seat, provides, usually executed chronologically. The team has learnt that the FFD can be important to the design of the seat for the following reasons:

- Discourages single-point solutions – the FFD provides the big picture and offers an overall point-of-view rather than a single subjective viewpoint
- Encourages design for creativity; opportunities are created via secondary functions that improve reliability or user-friendliness
- Clearly depicts functions that can be performed in parallel along with the ones that can be performed in series
- Shows points at which alternate paths can be taken
- Creates an initial understanding of the entire systems operation
- Provides an idea of where systems operations may be simplified
- Clarifies and categorizes systems requirements and specifications

With this in mind, the team saw many benefits that an FFD would bring to the entire seat design process, and set out to devise one for a civilian aircraft seat. The result of that is depicted in Figure 2.1.

This diagram was put together after an extensive brainstorming session by the group. Each person submitted a list of functions and movements that a typical passenger would tend to perform during a long flight. Having a team based entirely of international students of various nationalities would mean that each person would have experienced extensive flying from his/her home country, up to more than twenty hours, in order to get to the United States. This made each team member's contribution to this FFD very worthy.

As can be seen in the diagram, the FFD charts progress in flight, right from the moment the passenger gets on the plane, to the time he steps out of the aircraft once he reaches his destination. The team attempts to make the FFD as detailed as can be, making even the lesser actions of the passenger, such as 'look out window' clear in the diagram.

Among the discoveries stemming from this FFD are that:

- The passenger examines seat features the moment he turns up at the seat. This would suggest that the visual interior of the aircraft, seat included, is highly important. The typical passenger would take note of this more than the technical aspects of the aircraft
- The passenger would tend to fiddle around with the adjustable features immediately after he takes his place in his seat, and not at any other time. Those features that are not noticed by the passenger at this stage of experimentation are usually not utilized in the duration of the flight

These points will prove useful when the team focuses on the concept design process. Yet there are many other functions and design requirements, for example passenger size and comfort levels, that the FFD does not explore. This shows a need for the team to investigate other forms of analysis to cover the inadequacies of the FFD.

Functional Flow Diagram

For A Typical Aircraft Tourist-Class Passenger in A Long Haul Flight

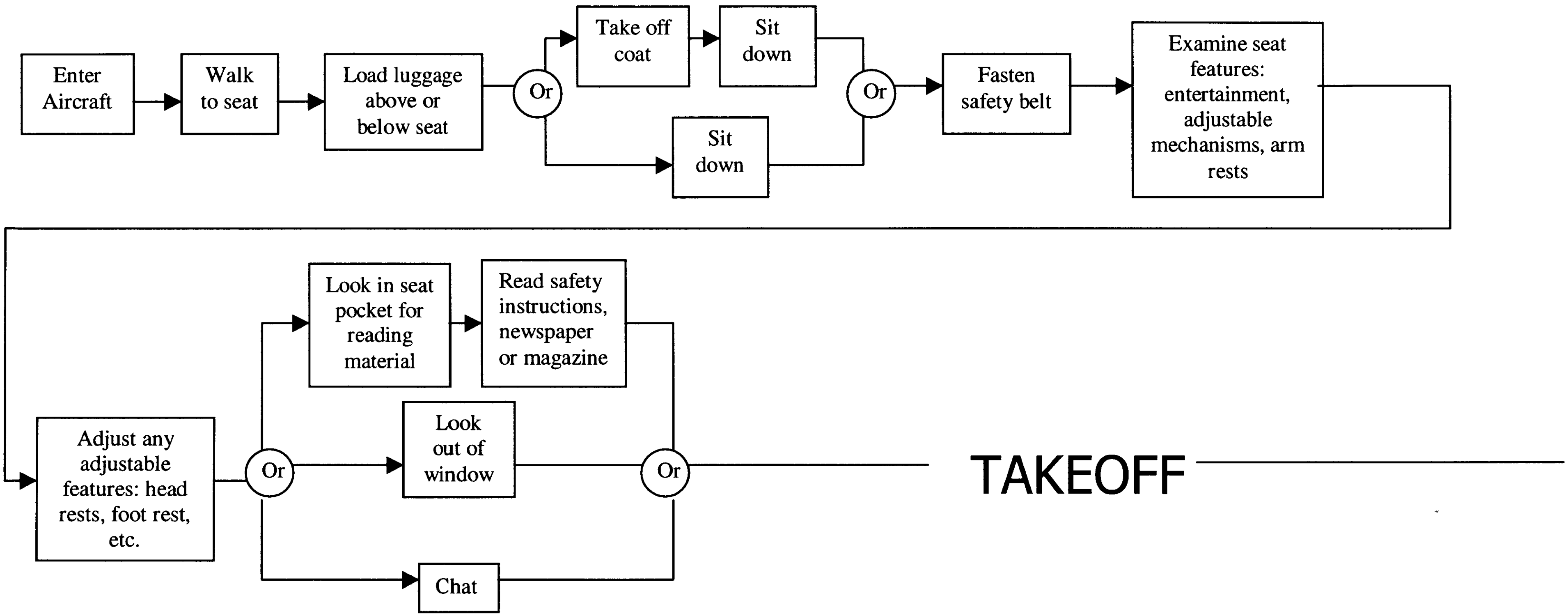

Figure 2.1: Functional Flow Diagram

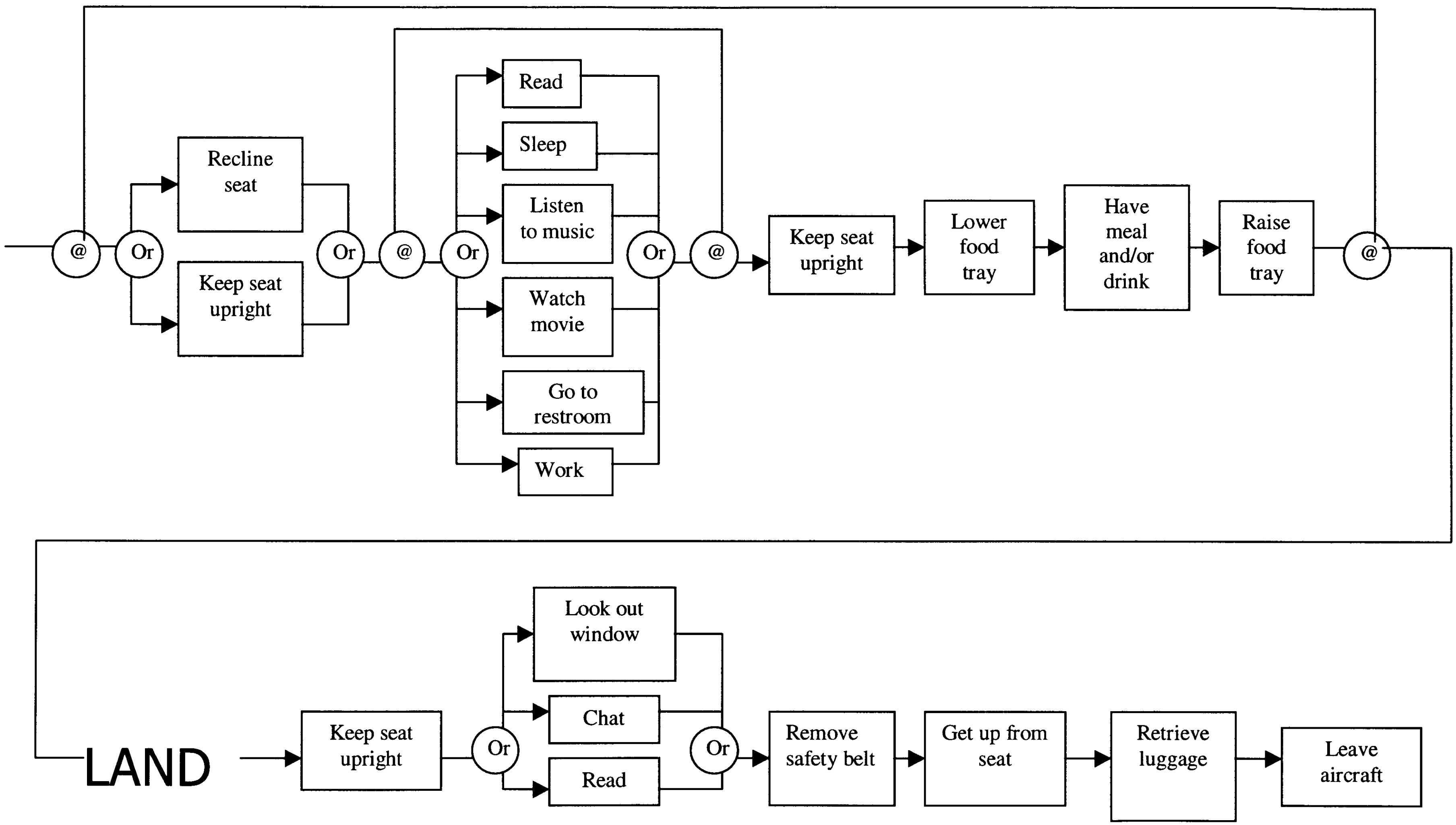

Figure 2.1: Functional Flow Diagram (cont'd)

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2.2 Customer Survey 1

For a product as common as a passenger seat in a civil aircraft, perhaps one of the best ways of gathering raw data from people who use the product is by means of customer surveys. In creating a high-quality information channel direct from the customer to the design team, close contact with the customers who have experience with the use of the product is extremely important – satisfying the customer is, after all, the motivation behind a more comfortable and functional seat design. The team agreed that distributing surveys, of which there were two, would be the most viable means of extracting customer information. This is based on the fact that a survey would gather the most data over a realistic time frame, which was in the order of weeks. Furthermore, surveys are also relatively inexpensive.

The low-cost nature of the surveys conducted in this project was largely due to the fact that they were done mostly on-campus. It was agreed that having just faculty, staff and students of the Institute participate in the surveys would save the project considerable postage, just by utilizing the cost-free interdepartmental postal system. It was also decided that the potential group of respondents could conceivably be representative of the general consumer population, since the on-campus population would possess a wide range of ages. The large number of international students and travelling faculty in this group would furthermore ensure that customer data would be sufficient for the purposes of this project.

The first survey of this project, shown in its entirety in the Figure 2.2, was prepared with the basic needs of the customer in mind. Its essential objective was to collect the most fundamental details on the customer; the demographics, habits, general opinions, and the plaudits or peeves that the consumer may have. As such, very fundamental questions were asked of respondents, like how often they fly, their satisfaction/dissatisfaction with the current seats in the market, and such. For this survey, much help was rendered by Mr. John Williamson of BE Aerospace. His experience in the field of aircraft seat design enabled the team to ask the right questions to get the necessary information required.

AIRCRAFT PASSENGER SEAT QUESTIONNAIRE I

Biographical Data:

Age ___ Height ____ Weight ___ Gender: Male / Female

Flying Habits

1. How many times do you fly in a year? 1 2-5 6-10 >10

2. On average, how many hours is each flight? 1-2 3-5 6-10 >10

3. What time of the day do you usually fly? Day Night

4. What class do you normally fly? First Business Economy

5. What airline do you prefer to fly by? ________________________

6. Why do you prefer this airline? Better Seats Personal Entertainment System
Food Quality Service Quality
Others (please specify) ________________

7. Please rate the percentage of flying time you spend engaged in each activity: Work___ Entertainment___ Food___
Sleep___ Others _______________

Opinions

8. What is the maximum you willing to pay for improvement of your seat (as a percentage of your fare)? <5% 5-10% 10-15% >15%

9. Which aspects of the seats do you think requires the most improvement? Head Rest Foot Rest Arm Rest
Back Support Passenger Space
Others ________________

10. Are there any airlines you remember having seats that are significantly more comfortable than the others? If so, please specify. Yes No
Airline:_________________

CONTINUED

Figure 2.2: Customer Survey 1

CONTINUED

Problems in Flight

11. Any physical effects at the end of the flight?

____

Seat Aspects

12. Rate the following aspects of the seats according to Excellent (1), Good (2), Satisfactory (3), Fair (4), Bad (5), or Simply Terrible (6).

a. Height	1	2	3	4	5	6
b. Width	1	2	3	4	5	6
c. Seat Fabric	1	2	3	4	5	6
d. Cushioning Comfort	1	2	3	4	5	6
e. Head Rest	1	2	3	4	5	6
f. Foot Rest	1	2	3	4	5	6
g. Arm Rest	1	2	3	4	5	6
h. Lower Back Support	1	2	3	4	5	6
i. Functionality for Slumber	1	2	3	4	5	6
j. General Comfort Level	1	2	3	4	5	6
k. Other ________________	1	2	3	4	5	6

13. Which of these features would you most like to see in passenger seats on your next flight?

Adjustable Lower Back Support Adjustable Head Rest Foot Rest

Better Overall Cushioning More Passenger Room

Other ______________________________________

Figure 2.2: Customer Survey 1 (cont'd)

2.2.1 Survey 1 Findings

Demographics

Of the people who so kindly responded, 71 or 58% were male and 51 (42%) were female. These respondents range from 18-year-old freshman to faculty in their seventies, which is indeed a highly diverse age spectrum. The mean was 34 years. Their heights also had a good range, from about 5 footers to those who stand six-and-a-half feet, averaging 5 feet 9 inches. Weight also had a similarly large range, from 100 to around 250 lb., a mean of about 155 lb.

Flying Habits

All respondents surveyed fly at least once a year. Just a little more than half (57%) of them make between 2 to 5 trips a year, a typical number for most. This is compelling data to suggest that an improvement in aircraft seating and seat comfort would certainly affect almost all people. And more than 90% of the respondents make trips that are on average more than three hours each way. About three-quarters of them have trips that are between three and ten hours, which is really a long time to be spending on a seat that is less than comfortable. This piece of information would later be the basis for our "flight testing", being 3 hours long for each subject. 85% of the respondents fly coach class, the seating category the team is to concentrate their design efforts on.

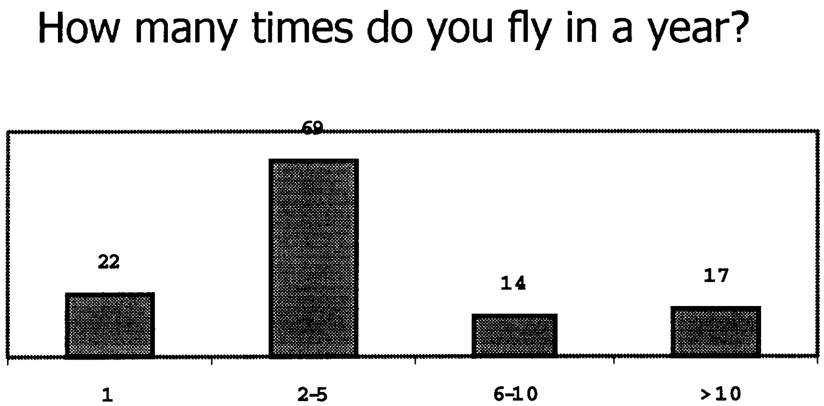


Figure 2.3: Survey 1, Q1

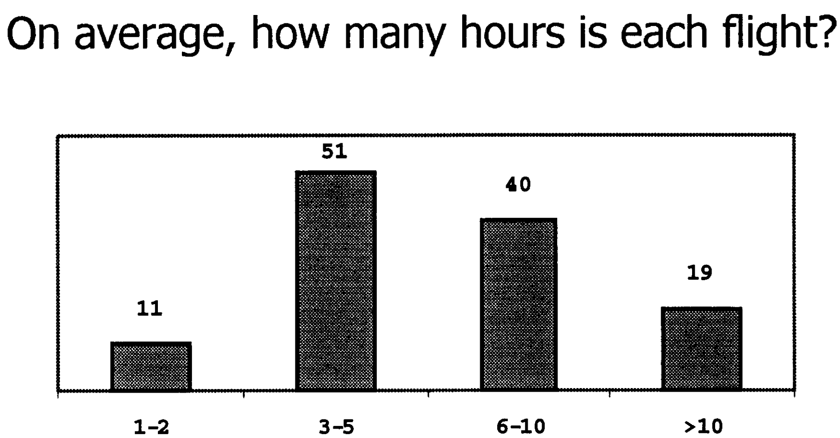


Figure 2.4: Survey 1, Q2

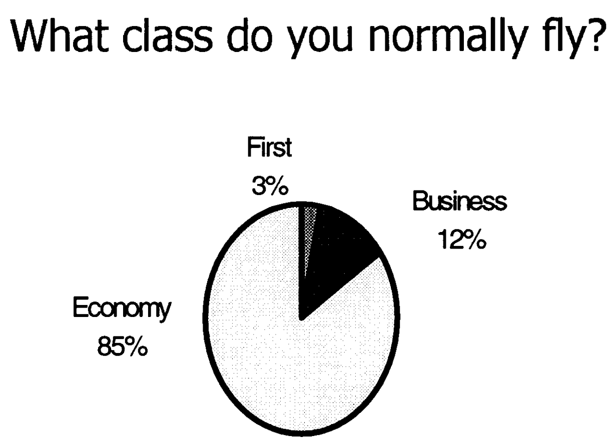


Figure 2.5: Survey 1, Q4

Customer Opinion

Almost all of the customers (98%) feel there is room for improvement in current aircraft seats. But naturally, most of them would want to see this improvement be at as low a marginal cost as possible. In fact, 66% would not be willing to pay more than 5% of their current airfare in order to see improve seats. This provides the impetus for the team to come up with a low cost design that at the same time accords significant improvement over the seats in use today. The number one demand of the passenger is space, as expressed by 57% of the respondents. A little less than half (47%) would not mind having considerably more support in the back area.

How much are you willing to pay for improvement?
(as a percentage of your fare)

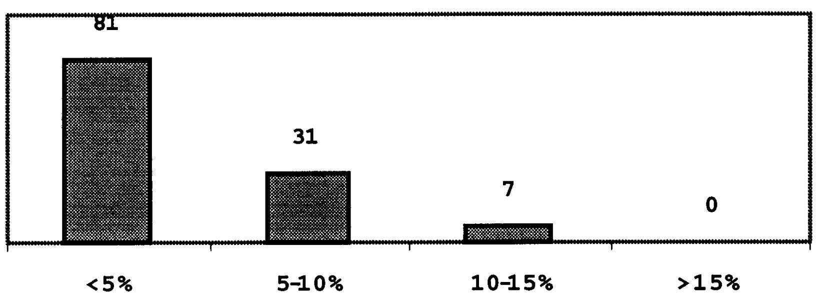


Figure 2.5: Survey 1, Q8

Which aspects of the seats do you think requires the most improvement?

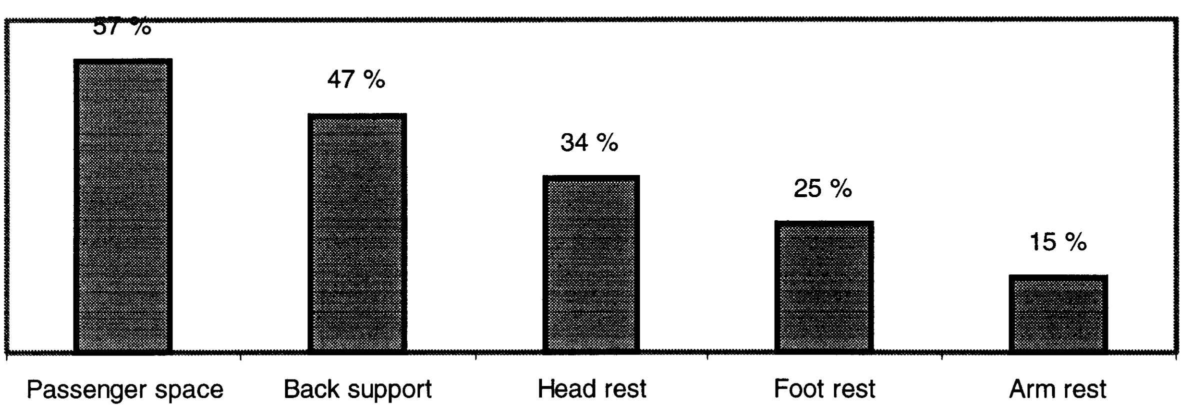


Figure 2.6: Survey 1, Q9

Seat Aspects

Almost all of the features found in today's seats found themselves between the Fair to Satisfactory category in the eyes of the customer. The two features that were actually Satisfactory to Good were Seat Height and Seat Fabric. Despite the name "seat" implying a primary function for sitting, from the results of the survey, it seems that there is a major complaint in the way seats are designed for sleeping. The lack of adequate back support again resurfaces as a customer grouse, something seat designers can definitely work on. As a result of all of the above, it is no surprise that more than 60% of the passengers would desire a greater amount of room, more than any other feature. On top of that, an adjustable back support would also be well received by customers in general.

Rate the following aspects of the seats
[Excellent (1), Good (2), Satisfactory (3), Fair (4) or Mediocre (5)]

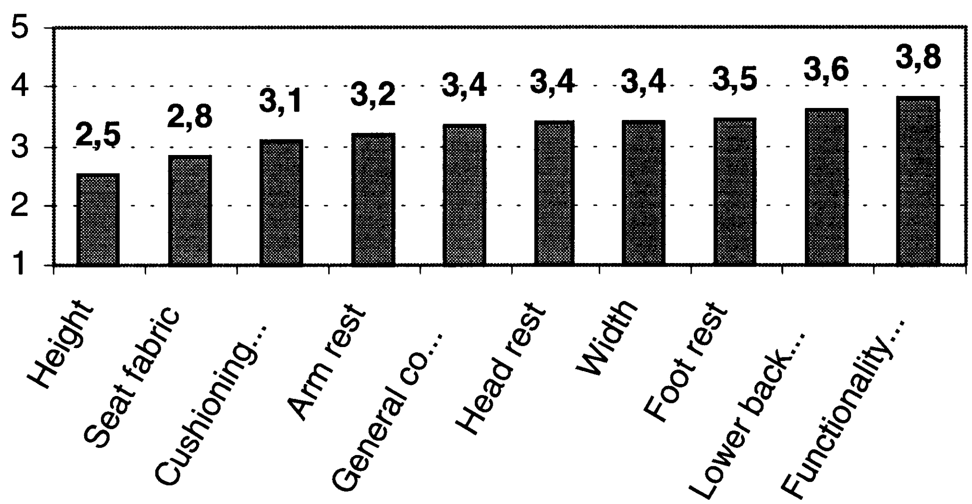


Figure 2.7: Survey 1, Q12

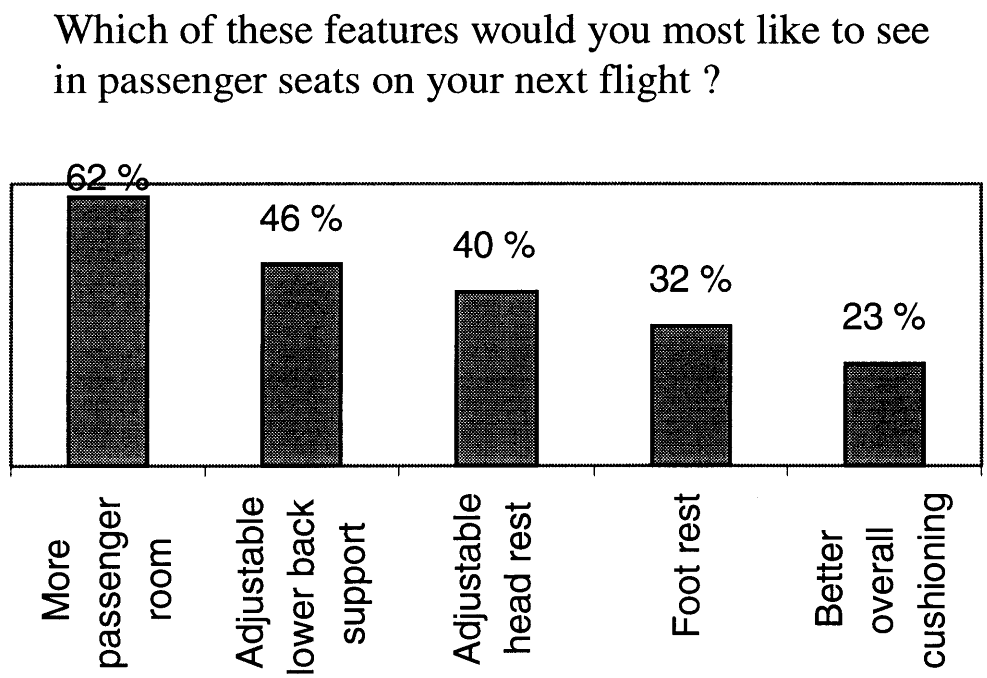


Figure 2.8: Survey 1, Q13

General Remarks from Survey 1

From this survey, what the typical customer is looking for is very clear. It is apparent that most of them are not very satisfied with the seats currently in use. Seating space per passenger and a better back support in the seat are things that the aircraft industry can definitely look into if passenger satisfaction is to be raised to a new level. And with the amount of flying that people generally do nowadays, an increase in comfort standards in aircraft seating will certainly affect the majority of people. There is without doubt a strong case for having more comfortable seats on board civilian flights.

2.3 Quality Function Deployment 1

Customer survey information was not only useful in the sense that the design team was able to realize what the customers wanted. It also provided much of the input for the team to construct a Quality Function Deployment (QFD). The QFD basically correlates technical requirements of a certain design with customer needs. The survey was a great aid to this process for the customer views included in the responses, especially in the comments section at the end of the survey. It was in this portion of the survey that the respondents made their strong opinions heard. And there were quite a few strong opinions on the subject. This allowed the team to pick out, in the customer's words, what they really wanted in the seat.

But why was a QFD required? The team needed some knowledge as to what direction the design should head for. Indeed there are many technical requirements that a good should possess, but which are the ones the team should hold in greater importance and which are those it should consider only when others have been fulfilled? There needs to be a prioritization of needs as well as requirements where this project is concerned, and the team feels that the QFD matrix is an excellent way of systematically ranking the requirements in order of importance (in the sense of fulfilling customer need). One other considerable benefit of the QFD process that the team recognizes is that it minimizes human bias, and furthermore forces the team to consider each customer need and technical requirement with respect to one another. QFD is generally a good objective tool for evaluating the relative importance of technical requirements, and on top of that, identifies conflicts between technical requirements.

For the first QFD (out of two), the team simply tried to brainstorm all the customer needs and technical requirements that could exist. Given the relative inexperience of the team in this subject, much advice was sought, and received, from BE's Mr. Williamson and respective faculty advisors. Finally the team came up with a detailed matrix that it believes covers most, if not all, of the factors that warranted consideration.

2.3.1 The Needs

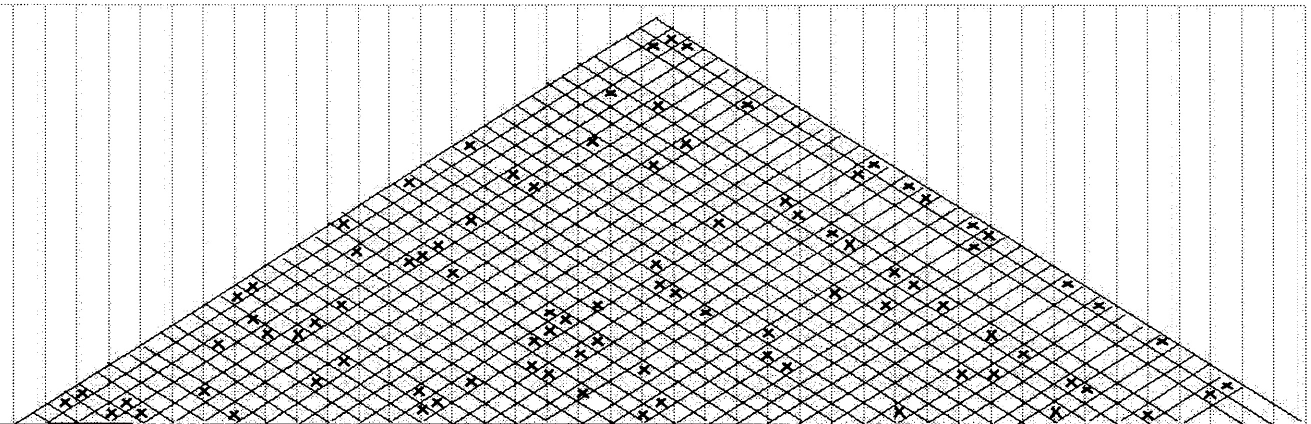
Where this project is concerned, the "customers" are not simply just passengers. It is felt that for the seat to successfully break into the market so that consumers can actually get to use them, the seat industry has to be a fellow beneficiary of the design. There must be incentive enough for seat manufacturers like BE Aerospace, aircraft makers and airlines to want to implement a new design. Thus the team considers industry an integral component of the whole concept of "customership".

A total of eighteen needs were devised. All of them fell into the categories of customer needs, industry needs, or both. Point weightings ranging from one to ten, in ascending order of importance, were assigned for each need. Those that fulfilled both customer and industry needs were taken note of for their dual fulfillment of needs and given a higher weighting accordingly.

2.3.2 The Technical Requirements

These are the general good engineering practices that would be found in any worthy engineering design plus other traits of design that would be found desirable in this particular design of the seat. Numbering thirty-seven, these technical requirements are devised according to the customer need; that is, the team would scan down the list of customer needs one by one, and then come up with technical requirements that would fulfill that particular customer need. Of course, many of these requirements fulfill multiple needs. These are the ones that the team was most interested in.

Requirements would then be assigned values by the team members according to the relationships they would have with each need – 9 points for a strong relationship, 3 for moderate and 1 for weak. Taking the example from Figure 2.9 and looking at the requirement "Reduce Seat Volume", the team decided that it has a *strong* impact on passenger ingress/egress and personal space (nine points each), have a *moderate* effect on improving physical comfort and lowering the weight of the seat (three points each), and also lowering cost of ownership to a *small* extent (1 point). Reducing the seat volume has *no* effect at all on the rest of the customer needs like anthropometric design or better entertainment for the passenger. As a result, this requirement has a total score of 175 points after adding up the component scores. This is done for all the technical requirements and the scores, can then be compared to see which are the most desirable technical requirements.



	Weighting	Accessory arrangement/minimization	Improved seat arrangement	Electrical controls	Mechanical controls	Simplicity of engineering	Durable materials	Reduced seat volume	Ergonomic/anthropometric design	Easily obtainable parts	Common internal parts	Low MTBF	Commonality of design	Minimize number of parts	Versatile design	Adjustable mechanims	Aesthetic design	Environmental controls	Light structural materials	Comfortable material	Ease of maintenance (cleaning too)	Personal avionics	Adjustable geometry	Variable loads absorption	Variable degree of firmness	Facilitate work	Intuitive controls	Isolation	Minimize controls	Powered adjustments	Modern appearance	Visual patterns	Material texture	Continuous adjustability	Fixed geometry	Modularity of design	Cost-effective design	Integrated funtionality		***CONSTRAINTS***	***Engineering standard***	***Compliance to regulations***
Customer needs																																										
Higher adaptability	8															9		3					9	3	1									9								
Better entertainment	7																					9						3														
Better environment	4	1	1	3														9				3						3														
Better ingress/egress	3	3	3					9															3																			
Additional functionality	7			9	9										9	3		1			3					9								3								
User friendly / Easy of use	1	3		1														1									9		9	9								3				
Customer/Industry needs																																										
Aesthetic appeal	7	1	1						3								9			3		1									3	9	3									
More personal space	10	9	3					9																														3				
Improved physical comfort	10	3	3					3	9							9		1		9			3	3	3									9								
Industry needs																																										
Lower cost of ownership	10				3	9	9	1		3	3	3	3	3					1		9																9	3				
Low weight	6	9		3		3		3						1					9																3			3				
High reliability	8	9		1	3	9	3					9		3																												
Spares provisioning	4	3				9	3			9	9	3		3																												
More robustness (stiffness, strength)	7					9								9																												
Improved maintainability	8	3			3	9				3	9		1	3							9															3		1				
Good fleet compatibility	5					3					9		9	3	3																											
High upgradability	5					3									9																					9						
Anthropometric (wider population fit)	8		1						9							9																										
Total		305	88	102	141	381	126	175	183	90	183	114	83	174	123	255	63	78	64	111	183	82	111	54	38	63	9	33	9	9	21	63	21	183	18	69	90	89			N/A	N/A

Figure 2.9: Technical Requirements Matrix

2.3.3 Results of QFD 1

The table below summarizes the most important technical requirements as devised by the QFD, their scoring, and the other requirements that are in conflict with them.

Rank	Requirement	Points	Conflict
1	Simplicity of Engineering	381	Ergonomic / Anthropometric Design Continuous Adjustability Adjustable Mechanisms
2	Minimize Accessories and Arrangement	305	Adjustable Mechanisms
3	Adjustable Mechanisms	255	Ease of Maintenance Simplicity of Engineering Minimize Accessories and Arrangement
4	Ergonomic / Anthropometric Design	183	Simplicity of Engineering
4	Continuous Adjustability	183	Simplicity of Engineering
4	Common Internal Parts	183	None
4	Ease of Maintenance	183	Adjustable Mechanisms

Table 2.1: Top Technical Requirements

The results appear very valid – simplicity and minimization are indeed vital requirements desired in every engineering design wherever possible, and adjustable mechanisms are the main source of adaptability for passenger needs and attributes.

2.4 QFD 2: The Product Design Matrix

The project's second Quality Function Deployment matrix is the result of extensive research done in a period of about a month. During this time, much information about seating, ergonomics, anthropometry and psychology had been unearthed to provide the team with a clearer understanding of what the entire business of seat design is about.

Over this period of intensive research, the team discovered and developed many ways to make an aircraft seat better. Many of these ideas were found from seating in other aspects of life, like office chairs, pilot seats and even dentist chairs. From this research phase, the team was able to come up with features that could be added to the baseline seat of today. There were no limits as to how small, or insignificant, so to speak, the features could be – all were to be ranked in the most objective way possible to come up with the features that would make the most improvement over the baseline seat.

The previous QFD exercise was met with considerable success in pointing out the more important technical requirements over the less. And it proved to be more than helpful in starting the ball rolling where the design process is concerned. A similar matrix could likely be more than helpful in similarly distinguishing the more viable and useful seat features from those that would not make as much of an impact.

Armed with the necessary technical requirements from the previous QFD, together with the possible seat features gathered over the research period, a plausible QFD-like matrix could be constructed. A standard QFD matrix has customer needs on the left column and technical requirements along the top row, with the relationship matrix indicating the links between the two. The team's new matrix would have technical requirements in the left column, with the possible seat design features in the top row. This would essentially retain the "needs vs. requirements" element of the standard QFD – the team's "needs" are now to fulfill the technical requirements, and the seat features are what is necessary to fulfill these technical requirements. The numbers in the matrix would represent the extent (still 9 for strong, 3 for moderate and 1 for small) to which the features satisfy the respective technical requirements. In replicating the QFD structure for the purposes of this project, a similar ranking can be constructed to help the team decide which features, or combinations of features, would help advance the seat to its best design concept.

The entire process in coming up with this matrix was not entirely different from that of the first QFD. Point weightings had to be assigned to each technical requirement (now in the leftmost column) according to relative importance. The input for this was the previous QFD, which ranked the requirements in order of importance. With the ranking, the team assigned weightings as to how important each requirement is, and the following is a list of the requirements together with their respective rating:

It was found that a scale of importance from 1 to 10 was insufficient to effectively distinguish the relative importance of each technical requirement. It was deemed that an upper limit of 20 would paint a more accurate picture by better decomposing each requirement for what it was worth.

Similar to the first QFD matrix, the team had to think up a few seat features that would satisfy each technical requirement, over and above the ones that were already conceived during the research phase. The result is 76 features that could improve the standard baseline seat used in the market today. The team then went through the entire process of assigning the relationship rating that links each technical requirement to every seat feature.

2.4.1 QFD 2 Results

Appearing in Table 2.2, the rankings gave a clear picture that out of all the features, the first two, the Non-Reclinable and Webbing features, were head and shoulders above the rest in terms of the requirements that they fulfilled. This can be seen from the almost-100 points that separated these two features and the rest of them. The non-reclinable feature was a strong contender for its uncomplicated concept. It scored very highly in contributing to simplicity of engineering, parts minimization and ease of maintenance. This would be a very attractive option for the manufacturers and airline operators for its cost-effectiveness. But this would involve taking away the most prominent feature in aircraft seats of today, and would no doubt leave the passenger with a compromised sense of comfort if there were no added frills to make up for taking away the recline feature.

The single-layer thin webbing concept scored highly in its simplicity and in accessory minimization, which will cut costs as described in the previous paragraph. But the most important benefit of reducing seat volume will result in great benefits for both industry and the consumer, in that more space can be freed up either to provide more seating capacity in the plane or to allow the passenger more room to maneuver, meaning a greater sense of comfort. This is a win-win situation for both parties, and definitely an idea worth looking into, which is the reason why the webbing concept in aircraft passenger seating forms the prime basis of this thesis.

Again, referring to the ranking in Table 2.2, the presence of three tray features in the top ten surely warrants a look at improvements that can be made on the trays in current seats. This is described in Bekiaris [Ref. 3].

#	Technical Requirements	Weighting	1. Patterns on fabric that give feeling of greater space	2. Aesthetically pleasing patterns of fabric	3. Colors that are pleasing to the eyes	4. Light colors to convey better sense of depth	5. Dark colors to make stains less visible	6. Space-age colors	7. "Slides" at the back of trays depicting sunset, mountain, etc. (selectable)	8. Logo/symbol on seat back to draw attention away from peripheral vision	9. Soft and comfortable fabric (nice to the touch)	10. Smooth fabric	11. Textured fabric	12. Durable and longlasting fabric	13. Zip-up seat covers (to facilitate cleaning)	14. Protruding seat edges to symbolically mark personal boundaries	15. Protruding head rest edges for more privacy	16. Retractable screens that block other passengers from field of vision	17. Seats arranged diagonally	18. Middle seats offset backwards to facilitate 3-way/4-way conversation	19. Theatre-style seating	20. Sliding trays	21. Tiltable trays	22. Height-adjustable trays	23. Height-adjustable arm rests	24. Inflatable arm rests	25. Arm rests that swing out to facilitate conversation (when seats are offset)
1	Simplicity of engineering	20	9	9	9	9	9	9	3	9	3	9	9	3	9	3	3	3				3	3	1	1	3	3
2	Accessory arrangement/minimization	16																									
3	Adjustable mechanisms	13							3									9				9	9	9	9	9	9
4	Ergonomic/anthropometric design	10																				9	9	9	9	3	
5	Ease of maintenance	10	3	3	3	3	9	3	1	3		3		9	9	3	3										
6	Continuous adjustability	10																9				9	9	3	3	3	9
7	Common internal parts	10																									
8	Reduced seat volume	9																									
9	Minimize number of parts	9																									
10	Mechanical controls	7							1									9				9	9	9	9	1	9
11	Durable materials	7											1	9													
12	Versatile design	6	3	3	3	3	3	3	3	3						3	3		3	9							9
13	Low MTBF	6					1							9													
14	Comfortable materials	6	3	3	3	3				3	9																
15	Adjustable geometry	6																							1	3	1
16	Electrical controls	5																									
17	Easily obtainable parts	5	3	3	3	3				3	1	1	1						1	1		1	1	1	1		1
18	Cost-effective design	5	3	3	3	3	3	1		3	1	3	3	1													
19	Integrated functionality	5	1	1	1	1	1	1	1	1	1			1		1	1					3	3	9	3	1	1
20	Improved seat arrangement	5																	9	9	3						
21	Commonality of design	4																									
22	Personal avionics	4																									
23	Environmental controls	4																									
24	Modularity of design	4	1	1	1	1	1	1		1	1			1													
25	Light structural materials	3																									
26	Visual patterns	3	9	9						3			3														
27	Aesthetic design	3	3	9	9	3	3	3	9	3											3		1				
28	Facilitate work (laptops included)	3														1	3			1		9	9	9	3	3	1
29	Variable loads absorption	3																								3	
30	Variable degree of firmness	2																								3	
31	Isolation	2							1	3						3	3	9	3								
32	Modern appearance	1		3	1			9	3	1	1							3	1	3	3		3			3	1
33	Material texture	1									9	3	9														
34	Fixed geometry	1														1	3										
	TOTAL:		331	352	323	304	337	270	181	320	153	243	235	291	280	133	141	361	85	120	37	477	483	407	365	304	414

#	Technical Requirements	26. Width-adjustable arm rest	27. Cup holder on arm rest	28. Cushioned arm rest	29. Sinkable (all the way) arm rest (instead of upwards rotation)	30. Contour head rest	31. Height-adjustable head/neck rest (mechanical)	32. Inflatable head rests	33. "Wings" to rest head on	34. Foldable head rest to facilitate front-back conversation	35. Adjustable foot rest	36. Adjustable leg rest	37. Vertically adjustable seat back	38. Horizontally adjustable backrest	39. Flat seat back	40. Contoured seat back	41. Concave contouring	42. Edge contouring	43. Pillow secured to the seat with velcro (position adjustable)	44. Electronic massage pillows	45. Adjustable lumbar support (mechanical)	46. Adjustable lumbar support (electrical)	47. Inflatable lumbar support	48. Pelvic support	49. Adjustable seat height (mechanical)	50. Inflatable seat bottom
1	Simplicity of engineering	3	9	9		3	1	1	3		3				9	3	3	1	9					3		
2	Accessory arrangement/minimization				3														1							
3	Adjustable mechanisms	9			3		9	9	9	9	9	9	9	9					3	3	9	9	9		9	9
4	Ergonomic/anthropometric design	3		3		9	9	3	1		9	9	9	3		9	9	9	3	3	9	9	9	9	9	3
5	Ease of maintenance		9	1		9									9	9	9	9	3							
6	Continuous adjustability	3			3		3	3	9	9	9	9	3	3							3	9	3		3	3
7	Common internal parts																									
8	Reduced seat volume														3			3								
9	Minimize number of parts					1										1										
10	Mechanical controls	3			3		9	1	3	3	9	9	9	9							9		1		9	1
11	Durable materials																									
12	Versatile design		9		9				9	9									1							
13	Low MTBF					3									3	3			3					3		
14	Comfortable materials			1																						
15	Adjustable geometry	9			9		1	3		9	1	1	9	1							1	1	1		1	3
16	Electrical controls																			9		9				
17	Easily obtainable parts		1	1			1		1		1				3				9		1					
18	Cost-effective design								1						9				1							
19	Integrated functionality	3	9	1	1		3	3					9	3		3					1	1	1	9	3	1
20	Improved seat arrangement																									
21	Commonality of design																									
22	Personal avionics																									
23	Environmental controls																									
24	Modularity of design																		1							
25	Light structural materials																									
26	Visual patterns																									
27	Aesthetic design			3		3			3							3	1	1		1						
28	Facilitate work (laptops included)		3	1						1				9											3	
29	Variable loads absorption			3				3											3				3			3
30	Variable degree of firmness							3															3			3
31	Isolation					1			3																	
32	Modern appearance			1	1	1	1	3	9			3				9	3	9		3			3	3		3
33	Material texture			3															1							
34	Fixed geometry					9									9	9	3	3						9		
	TOTAL:	337	393	271	262	298	367	266	396	349	441	379	409	298	394	319	259	252	393	130	326	363	283	236	340	236

#	Technical Requirements	51. Tiltable seat bottom (entire)	52. Downward foldable seat bottom (front edge) to facilitate ingress/egress	53. Tiltable seat bottom (front edge)	54. Sliding-out seats	55. Foldable seat bottom	56. Flip-over seat bottom	57. Lower seat bottoms (no luggage space)	58. Sideways rocking seat bottom	59. Non-reclinable seats	60. Thin diaphragm seats without cushions	61. Webbing as cushioning substitute	62. Sandwich structure in the cushion	63. Store hand items below seat (remove front pocket)	64. Bag/pocket hanging from seat bottom edge (remove front pocket)	65. Knee cushions	66. Seat to diagonal bed transformation	67. Personal entertainment system	68. Variable light intensity	69. Confor foam	70. Conventional foams	71. One type of foam	72. One type of structural material	73. One-type adjustment mechanisms (inflatable)	74. One-type adjustment mechanisms (mechanical)	75. One-type adjustment mechanisms (pneumatic/hydraulic)	76. One-type adjustment mechanisms (electrical)
1	Simplicity of engineering						3	9		9	3	9		9	9	9					9	9	9				
2	Accessory arrangement/minimization									9	9	9		9	9									1			3
3	Adjustable mechanisms	9	3	9	9	3	3		1								9	3	9					9	9	9	9
4	Ergonomic/anthropometric design	3	1	3	1	1		1	1							1	1							9	9	9	9
5	Ease of maintenance									9	9	9				1					3	3	3	1	1	1	1
6	Continuous adjustability	9	3	9	9	3			9								3		9					3	3	9	9
7	Common internal parts										1											9	9	9	9	9	9
8	Reduced seat volume		1			1					9	9		3	3												
9	Minimize number of parts									9	3																
10	Mechanical controls	9	3	9	9	3											9							1	9	3	
11	Durable materials										9	9									3						
12	Versatile design		9			9	3		3								9	9									
13	Low MTBF									9	3	3															
14	Comfortable materials															1				3							
15	Adjustable geometry	3	9	3	3	9											9							3	1	1	1
16	Electrical controls																	9									9
17	Easily obtainable parts									9						1					9	1	1		1	1	
18	Cost-effective design									9	1	1									9	9	9	1	1	1	
19	Integrated functionality	1		3		1	1	1				1					1	9									
20	Improved seat arrangement																										
21	Commonality of design									9											9	9	9	3	3	3	3
22	Personal avionics																	9									
23	Environmental controls																		9								
24	Modularity of design									9											1	3	3				
25	Light structural materials										9	9	3								1						
26	Visual patterns																										
27	Aesthetic design	9			9													9									
28	Facilitate work (laptops included)	9		3	9					9									9								
29	Variable loads absorption												9			3	1			9							
30	Variable degree of firmness						1						3							9							
31	Isolation																	9									
32	Modern appearance	1							3								3	9									
33	Material texture															3											
34	Fixed geometry							9		9	3	3															
	TOTAL:	388	227	352	362	232	134	214	144	757	529	626	52	361	361	233	349	283	280	73	374	327	327	324	367	375	437

Figure 2.10: Product Design Matrix

Rank	Feature	Score
1	Non-reclinable seats	757
2	Webbing as cushioning substitute	626
3	Thin diaphragm seats without cushions	529
4	Tiltable trays	483
5	Sliding trays	477
6	Adjustable foot rest	441
7	One-type adjustment mechanisms (electrical)	437
8	Arm rests that swing out to facilitate conversation (when seats are offset)	414
9	Vertically adjustable seat back	409
10	Height-adjustable trays	407
11	"Wings" to rest head on	396
12	Flat seat back	394
13	Cup holder on arm rest	393
14	Pillow secured to the seat with Velcro (position adjustable)	393
15	Tiltable seat bottom (entire)	388
16	Adjustable leg rest	379
17	One-type adjustment mechanisms (pneumatic/hydraulic)	375
18	Conventional foams	374
19	Height-adjustable arm rests	365
20	Adjustable lumbar support (electrical)	363
21	Sliding-out seats	362
22	Retractable screens that block other passengers from field of vision	361
23	Store hand items below seat (remove front pocket)	361
24	Bag/pocket hanging from seat bottom edge (remove front pocket)	361
25	Height-adjustable head/neck rest (mechanical)	357
26	One-type adjustment mechanisms (mechanical)	357
27	Aesthetically pleasing patterns of fabric	352
28	Tiltable seat bottom (front edge)	352
29	Foldable head rest to facilitate front-back conversation	349
30	Seat to diagonal bed transformation	349
31	Adjustable seat height (mechanical)	340
32	Dark colors to make stains less visible	337
33	Width adjustable arm rest	337
34	Patterns on fabric that give feeling of greater space	331
35	One type of foam	327
36	One type of structural material	327
37	Adjustable lumbar support (mechanical)	326
38	One-type adjustment mechanisms (inflatable)	324
39	Colors that are pleasing to the eyes	323
40	Logo/symbol on seat back to draw attention away from peripheral vision	320
41	Contoured seat back	319
42	Light colors to convey better sense of depth	304
43	Inflatable arm rests	304
44	Contour head rest	298
45	Horizontally adjustable backrest	298
46	Durable and long-lasting fabric	291
47	Inflatable lumbar support	283
48	Personal entertainment system	283
49	Zip-up seat covers (to facilitate cleaning)	280
50	Variable light intensity	280

51	Cushioned arm rest	271
52	Space-age colors	270
53	Inflatable head rests	265
54	Sinkable (all the way) arm rest (instead of upwards rotation)	262
55	Concave contouring	259
56	Edge contouring	252
57	Smooth fabric	243
58	Textured fabric	235
59	Pelvic support	235
60	Inflatable seat bottom	235
61	Knee cushions	233
62	Foldable seat bottom	232
63	Downward foldable seat bottom front to facilitate ingress/egress	227
64	Lower seat bottoms (no luggage space)	214
65	"Slides" at the back of trays depicting sunset, mountain, etc. (selectable)	181
66	Soft and comfortable fabric (nice to the touch)	153
67	Sideways rocking seat bottom	144
68	Protruding head rest edges for more privacy	141
69	Flip-over seat bottom	134
70	Protruding seat edges to symbolically mark personal boundaries	133
71	Electronic massage pillows	130
72	Middle seats offset backwards to facilitate 3-way/4-way conversation	120
73	Seats arranged diagonally	85
74	Confor foam	73
75	Sandwich structure in the cushion	52
76	Theatre-style seating	37
	Average:	308

Table 2.2: Features Ranking

2.5 Customer Survey 2

After about a month of research and gathering of information from knowledgeable sources and the internet, the team got together and decided that a supplementary survey was required. It was suggested by Mr. Williamson from BE Aerospace that such social surveys are not very often performed in industry, and are indeed extremely helpful in identifying and furthermore addressing problems where aircraft seats are concerned. The team was encouraged to extract more data by this means and resolved to narrow down the discussion in the survey, making it inclined more towards the subject of passenger comfort with respect to the variations in flight activities.

Mr. Williamson, during the System Requirements Review, expounded on the subject of Emphatic Testing. This type of testing aims to find out what activities the passenger engages in, and how much time each passenger allots to each particular activity. This information will enable the team to better recognize the more important features that are to be included in the seat.

Due to limitations in the funding and the time frame of this project, it would not be possible to perform tests similar to those that industry already carries out, but it is hoped that this second survey can achieve a certain measure of reliability on this piece of information, based on the passenger's recollection and estimation of what she does in a typical flight. On top of this, the surveys reveals elements that cause (dis)comfort for the passenger and also more specific customer opinion on certain seat features.

But having done the second QFD matrix prior to this survey, the team has in mind the three main design concepts, mentioned above, that were emphasized in the matrix when devising the survey. Some of the questions asked measure customer sentiment on these new design concepts, such as whether or not they would mind not having a recline feature on the seat, or whether they would desire improvements being made to the tray in front of them.

AIRCRAFT PASSENGER SEAT QUESTIONNAIRE II

1. Biographical Data:

Age ___ Height ____ Weight ___ Gender: Male / Female

2. Flying Habits

i. How many times do you fly in a year?	1	2-5	6-10	>10
ii. What is the most common flight duration?	1-2	3-5	6-10	>10 hrs
iii. What class do you normally fly?	First	Business	Economy	

3. Flight Activities

Rate the level of comfort experienced during these activities:
(Excellent – 1, Good – 2, Neutral – 3, Poor – 4, Very Poor – 5)

a. Getting in/out of:

(i) aisle seat with front seat upright	1	2	3	4	5
(ii) aisle seat with front seat reclined	1	2	3	4	5
(iii) window seat w. front seat upright	1	2	3	4	5
(iv) window seat w. front seat reclined	1	2	3	4	5

(For the activities below, please also indicate the percentage of time spent on each activity.)

b. Reading	_____% of time	1	2	3	4	5
c. Working (writing, operating laptop, etc.)	_____% of time	1	2	3	4	5
d. Eating	_____% of time	1	2	3	4	5
e. Sleeping	_____% of time	1	2	3	4	5
f. Chatting	_____% of time	1	2	3	4	5

CONTINUED

Figure 2.11: Customer Survey 2

CONTINUED

4. Preferences:

a) How much would you desire a seat that provides
privacy/isolation? (Very much) 1 2 3 4 5 (Not at all)

b) Do you usually recline your seat during flight? Yes____ No____

c) How disturbed are you when the person in front reclines his/her seat? (Very much) 1 2 3 4 5 (Not at all)

d) How much would you be willing to trade off the recline feature of the seat for an adjustable back support? (Very much) 1 2 3 4 5 (Not at all)

e) Would you rather have the magazine/safety card storage pocket below your seat than in front of you? Yes____ No____

f) How much would you desire:

(i) a sliding in/out tray? (Very much) 1 2 3 4 5 (Not at all)

(ii) a tilting tray (Very much) 1 2 3 4 5 (Not at all)

(iii) a height-adjustable tray (Very much) 1 2 3 4 5 (Not at all)

g) Rank the following seat fabric colors in order of preference:

Blue____ Green_____ Blue-green_____ Red_____

Figure 2.11: Customer Survey 2 (cont'd)

2.5.1 Survey Results

Seat Ingress/Egress

It can be seen from the bar charts in Figure 2.12 to 2.15 that most passengers find conditions for getting in and out from seat to aisle favorable only when the passenger is occupying the aisle seat *and* when the seat in front is not in recline. Entering and exiting the window seat when the seat in upright is not a favorable situation for more than half of the passengers. When the front seat is in recline, more than half of the respondents rated conditions as "Poor" or "Very Poor", whether he is occupying the window or aisle seat. In fact, as many as 88% of the respondents rated conditions in these two negative categories when occupying the window seat.

This data is evident of the fact that passenger space is a considerable problem in commercial aviation, or at least in the case of passengers moving from seat to aisle. It suggests a lack of space for movement, which is not only a case of inconvenience for the passenger, but, in a more dire context, could prove to be a safety hazard. In the case of emergency, difficulty in moving from the passenger's sitting location to the respective nearest exit could mean loss of life and, from the data, especially so if passengers neglect to move the seatback upright, something which could very well happen in times of panic. A greater amount of passenger space would facilitate greater fluidity and fewer hassles in the movement of passengers, whatever the scenario.

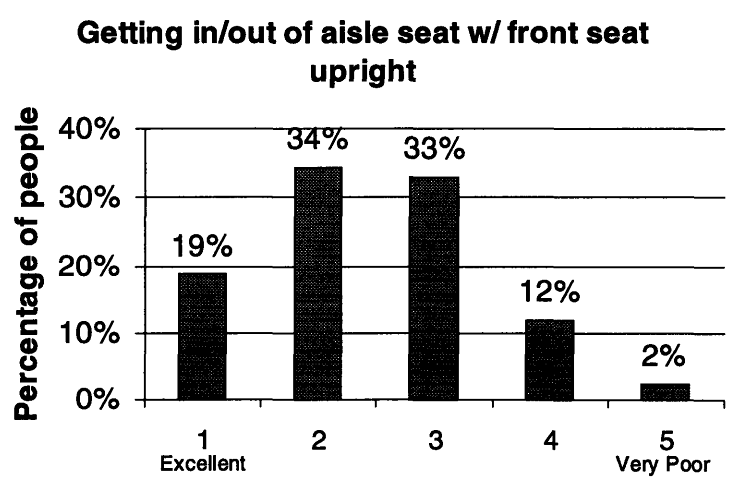


Figure 2.12: Survey 2, Q3a(i)

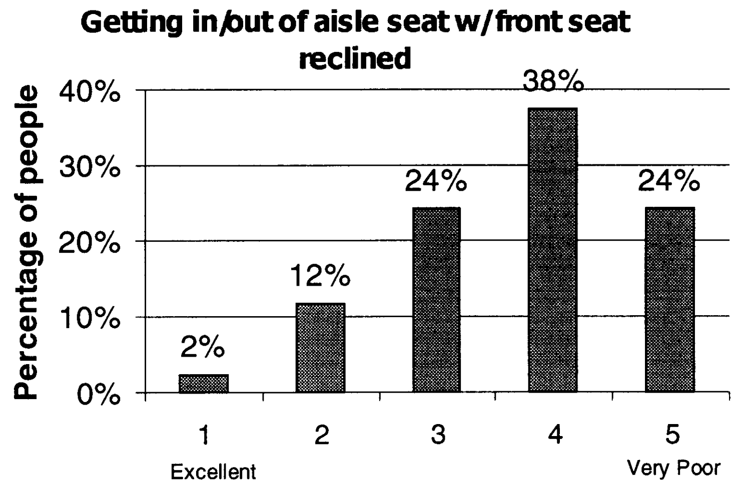


Figure 2.13: Survey 2, Q3a(ii)

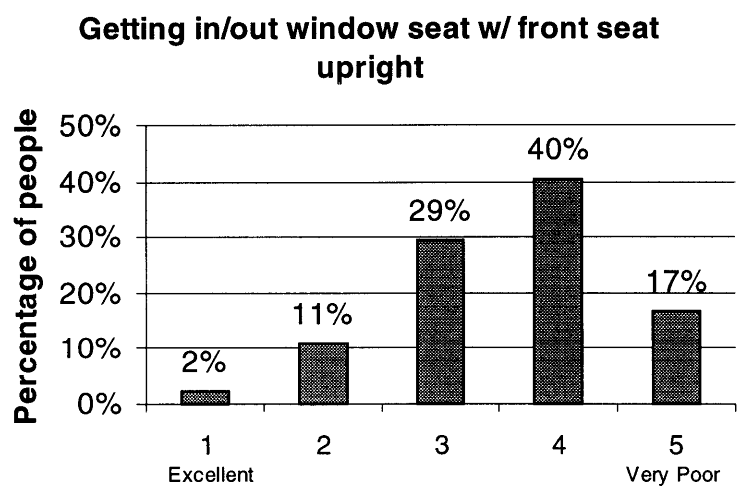


Figure 2.14: Survey 2, Q3a(iii)

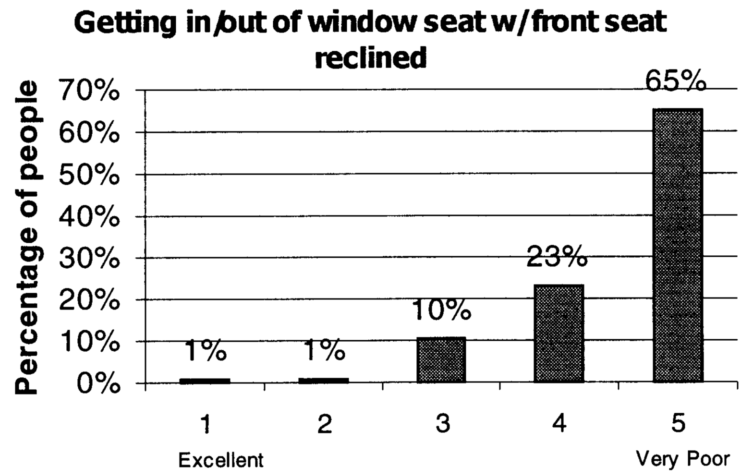


Figure 2.15: Survey 2, Q3a(iv)

Proportion of Time Spent on Each Flight Activity

Figure 2.16 shows the flight activities that take up most of the passengers' time. The act of reading takes up the greatest amount of flight time for 45% of the passengers. Working is top of the activity list for about a quarter of the respondents. This suggests that the seat design would have to sufficiently facilitate these activities to be successful and practical.

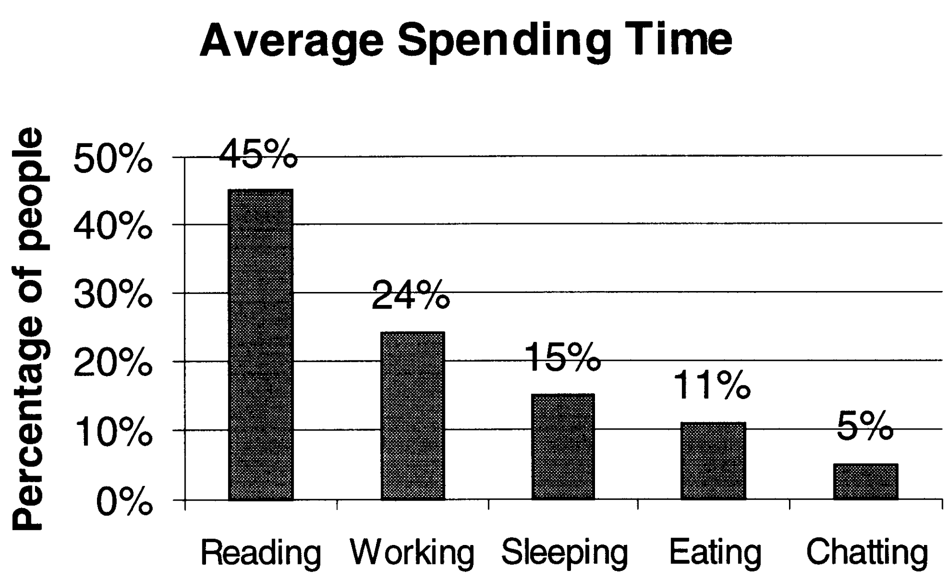


Figure 2.16: Survey 2, Q3b-f

Passenger Comfort During Fligh

Respondents were quizzed for level of satisfaction with current seats with respect to comfort levels when engaged in their various activities. From the charts in Figures 2.17 to 2.20, passengers are generally satisfied with the comfort that current seats provide for reading, but definitely not for eating, working or sleeping, where more than half of the respondents rated the seat "Neutral" and below. This phenomenon is found to be worst in the act of sleeping, where more than half of them voted seats to be rock bottom in the "Very Poor" category. This suggests that while current seat designs require more work in terms of working rather than in reading, they are not doing much to help the passenger sleep well.

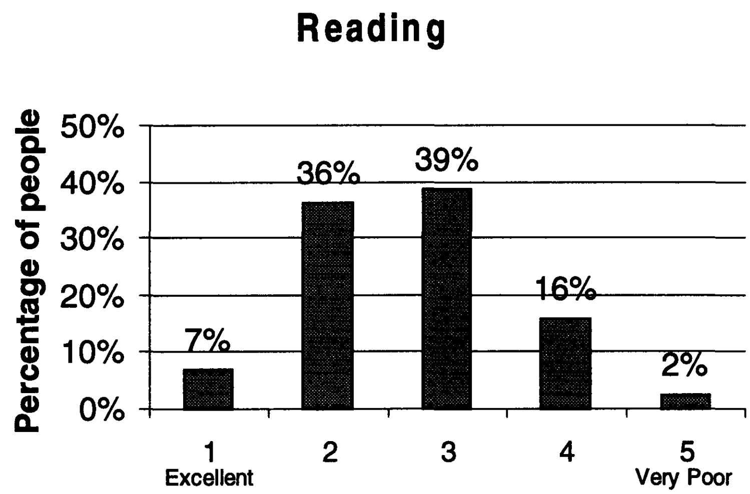


Figure 2.17: Survey 2, Q3b

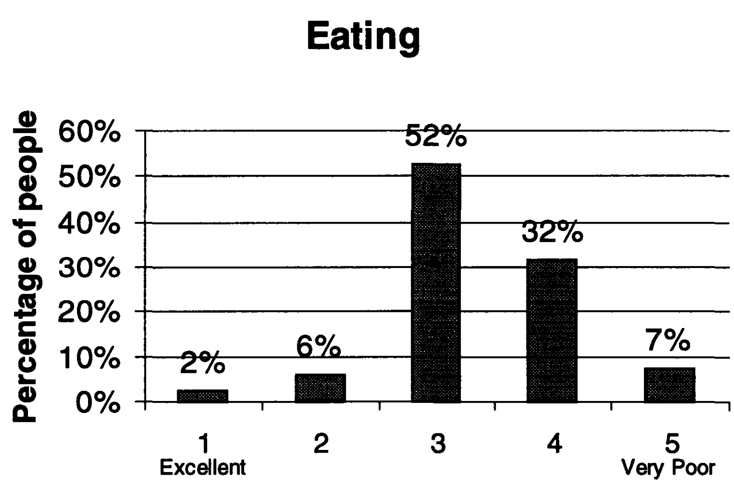


Figure 2.18: Survey 2, Q3d

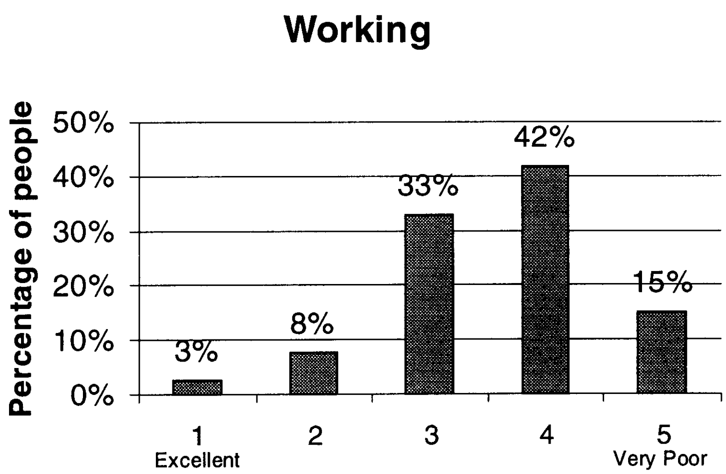


Figure 2.19: Survey 2, Q3c

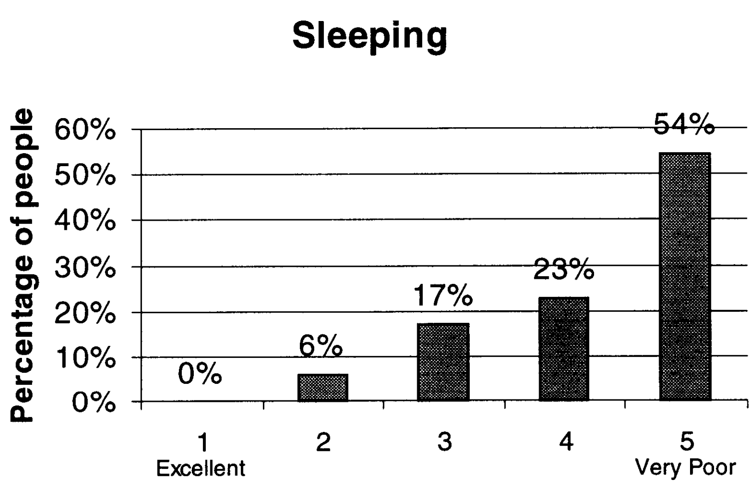


Figure 2.20: Survey 2, Q3d

Disturbance when Front Seat Reclines

Two in three feel disturbed when the seat in front of them reclines. The team feels this is another concern of passenger space. While passengers feel they are not able to use the tray for work or other purposes when the seat in front of them is in recline position, their personal space is also violated, taken up by the seatback moving toward them.

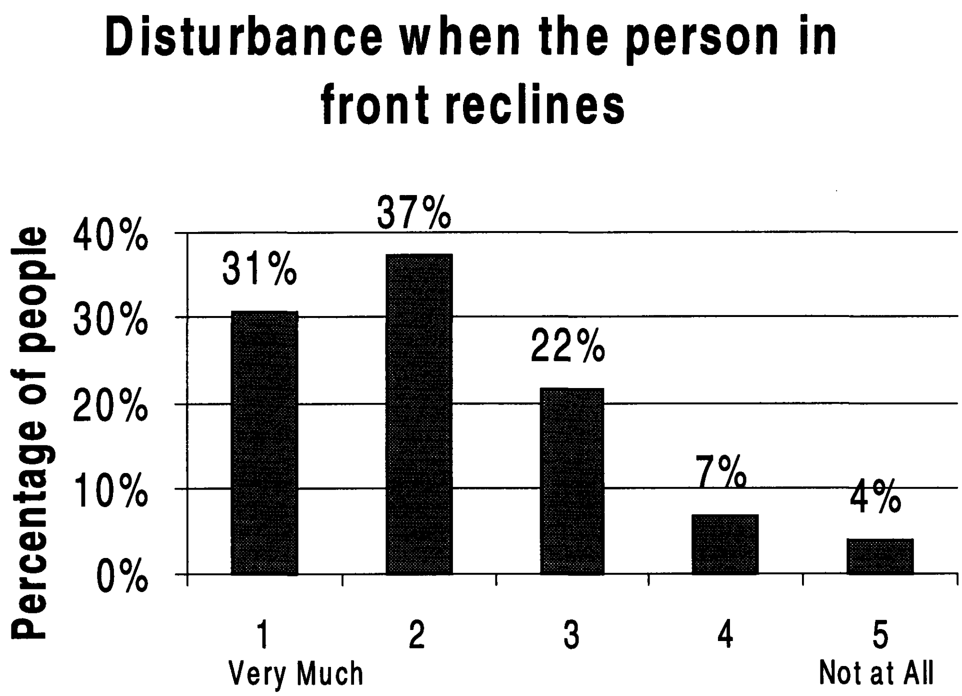


Figure 2.21: Survey 2, Q4c

2.6 Overview

This analysis of requirements opened the eyes of the project team in that it was informed of the overall needs of the design. The team realized the major problems that passengers face – chief of which was the issue of personal space. The two QFD matrices gave a good overall view of what steps to take to ensure that not only the passengers' problems are solved, but furthermore in the most cost-effective and practical ways possible. From this analysis it was found that the webbing concept would be a promising means of providing passengers with the comfort that they require, and industry with the cost-effectiveness needed. Subsequent chapters will dwell on more specific exploration of the webbing concept in aircraft passenger seats, and further develop webbing as part of a design concept that could work for airlines and air travelers alike.

Chapter 3 – The Webbing Concept and Design

The idea of having a single layer of enmeshed material to act as the only form of cushioning in a flight of considerable time sounds like a radical concept at first. Foam cushioning has been a mainstay of aircraft passenger seats for a long time now. People have been used to the idea of thick foam padding as the main, if not only means to providing comfort. Such is the extent, that people have the perception of comfort being directly proportional to the amount of foam cushioning being used, or how thick or "luxuriant" a chair looks. A case in point: people tend to look towards a well-padded, "fat"-looking seat with abundant and conspicuous cushioning for a comfortable ride. They would be inclined to shun those that appear "slim", thinking them too bare and probably be too harsh on a human body over a long period of time.

This chapter introduces the idea of webbing as a highly feasible method of providing cushioning that is comparable, if not superior, to the foam cushions in use in today's aircraft passenger seats. One would find that, with its many advantages over conventional foams, webbing is, indeed, one for the future where seat cushioning is concerned. This chapter also follows how the team managed to integrate the webbing concept into a seat prototype fit for testing.

3.1 The Case for Webbing as a Substitute for Foam Cushioning

3.1.1 Concept Conception

The webbing concept was initially discovered in a book named *Chairs* [Ref. 1]. It basically tracks the development of the various lines of seating over the history of mankind. It was not as if webbing chairs were getting much mention in the book – it was just a small, innocuous-looking illustration, just enough to illustrate to the reader just what webbing meant. Yet in that picture, the merits of having a webbed seat, to be elaborated later in this chapter, were apparent. Sufficiently apparent, it seems, for the idea to be raised in the next project meeting, and for it to be included in the Product Design Matrix. From then on in, the credibility of the idea led the team to deem it worth building a prototype for and, furthermore, testing.

3.1.2 Previous Uses of Webbing

To consider webbing an entirely new wave form of support is an anomaly. Indeed it, or rather the concept, has been around for some time. One of the most common uses of webbing is in the hammock. Not precisely what one would call cutting edge, but nevertheless the very idea on which this simple resting device is based. One of the most attractive advantages of the hammock as a good thing to bring on one's travels is that it does not weigh much at all. It is this same quality that endeared the team to the concept, and helped it score points in the Product Design Matrix.

Though it would be wrong to say that the webbing concept is a wholly fresh notion in aeronautical applications. Already it is found in military transport aircraft, like the Hercules C-130, which are used to lift ground troops. The webbing that these troops sit on consists of thin bands of nylon, perhaps two inches wide, woven loosely together in a cross-meshing structure and attached to an aluminum frame. This type of cushioning is not the most comfortable, but nevertheless serves the necessary purposes in this context. This is mainly due, in this particular case, to its low-cost attribute. That it is also lightweight and comfortable enough to serve a military application makes webbing very ideal indeed.

Other current uses of webbing include the rattan chair in which thin strips of wood are tightly woven together in a similar way as in the C-130 seats to form the seat bottom and back of a chair.

3.1.3 Advantages of Webbing over Foam

Despite it being the natural choice for airline seat cushioning, foams come with many disadvantages where its aeronautical application is concerned, such as flammability. Yet it is believed that foams were used due to a lack of a better alternative. From the kind invitation of Mr. John Williamson, the team made a visit to the facilities at BE Aerospace in Litchfield, Connecticut. One of the most significant facts learnt from the visit was how inadequate conventional foams were as airline seat cushions. The team feels that the webbing concept *is* the viable alternative that can outperform foam cushions for the following reasons:

Cabin Space

During the plant visit at BE, the team was told that one of the most glaring disadvantages of foam cushions is the amount of space it has to take up to provide the amount of cushioning required. Conventional tourist-class seats have at least a three-inch layer attached to the aluminum-cum-fiberglass frame all-round, perhaps more for additional padding or contouring. In this area, foam is up against webbing which stands at a quarter of an inch thick at the most. This translates into more than one and a half cubic feet of space savings per seat in the tourist class. For the passenger, it could mean more room to maneuver, resulting in greater comfort levels, and more space for carry-on luggage. For the airline, this suggests either greater customer satisfaction or more space to incorporate extra seats into the plane; both cases generating more revenue. Airline seats could definitely do with these benefits.

Weight

Together with seat volume comes the subject of weight. Conventional foams do not come light – especially with a hard flotation foam entrenched in the seat bottom – as compared to a single layer of webbed material. Made from lightweight elastomeric compounds, the current technology in webbing ensures it is light as much as it is thin. This has major cost implications. The reduced weight that results from having foams substituted with webbing would mean lower fuel consumption, shorter flight hours or the ability to carry more passengers or cargo.

Cost

Granted that the initial outlay of an airline replacing their foam-cushion seats with webbing would be rather substantial, the long-term financial benefits cannot be ignored. Customer satisfaction, extra seats, lower fuel consumption all lead to lower cost of operation and increased revenue for the airline over a sustained period of time. This could plausibly recoup the cost of adoption by a certain period of time, after which this reduced cost and increased revenue would be considered for the airline.

Flammability

There is no doubt that the foam used in current seat cushions is flammable. Given the high level of concern over safety issues, this is a big problem. Manufacturers get over it by covering the foam with a fire-retardant fabric, which effectively adds an extra layer to the already-bulky seat. Another one of this project's industry supporters, Miliken, claims that webbing cushions can be made out of fire-retardant elastomers. And not only are they fire-retardant, their emissions as a result of fire are also non-toxic. This essentially passes all relevant fire regulations set by the Federal Aviation Authority (FAA). Thus the thin layer of webbing would not even need an extra outer layer that the foam does, giving it an added advantage. Having a single bare layer of webbing would also be an edge over multiple layers of foam and fire-retardant fabric in terms of ease of maintainability.

Ergonomic Comfort

The office chair-making company Herman Miller, in its website, claims that their webbing chairs are ergonomically more comfortable than conventional chairs. This will be put to the test during the seat prototype evaluation phase of this project. It is further stated that their webbing causes pressure distribution to the correct areas of the sitting body, something that conventional foams are not able to do. The testing to be done in the latter stages of the project would either substantiate or disprove this claim.

Ventilation

But for at least one aspect of seat comfort, there is no doubt. The porous nature of the webbing concept allows the sitting body to "breathe". A characteristic of foam cushions that many users dislike is the build-up of body heat in the cushion over a long period of time. This build-up may cause perspiration or other forms of heat-induced bodily discomfort in the passenger. In the permeable webbing, chances of heat build-up are extremely remote, as air passes through the webbing surface with ease, facilitating good ventilation between the passenger's body surface and the cushion surface, a phenomenon that would be impossible in foam cushions. This is a definite plus that webbing has over foams where passenger comfort is concerned.

Durability

The project has heard claims from the Miliken representative, Mr. Gettys Knox, that a webbing is more durable than an ordinary foam cushion. This translates to reduced cost for the airline and aircraft manufacturers derived from reduced replacement rate.

Waterproofing

Being a thin layer of elastomer that is impermeable to water, the webbing cushion is resistant to spilled liquids unlike the foam cushion. Webbing also does not stain, and so does not have to be replaced as often as the foam. On the whole, it is a much more robust material compared to foam.

3.2 The Design Process

Once the team was convinced of the advantages webbing has to offer over foam cushions, both from intensive research and the Product Design Matrix, it quickly went into the seat design phase of the project.

3.2.1 Seat Features

In an effort to concentrate the design on passenger comfort, it was decided that the two design concepts that were created would have to fulfill the following three important comfort categories:

- Increased personal space
- Facilitation of in-flight activities
- Greater physical comfort

These characteristics were deemed most important to passenger comfort from the list of customer needs in the first QFD matrix, where they were given the highest weighting. It was felt that the customer need, "higher adaptability" could be defined better. And so in this situation, it became "facilitation of in-flight activities", meaning the ability of the seat to allow the passenger to carry out a variety of activities like laptop working, reading, writing etc.

These three categories provided the basis on which the team would select their seat features and furthermore combine them to form seat concepts. It was decided that webbed cushioning would form the backbone of one of the two seat concepts. This fulfilled the personal space and physical comfort functions. An improved tray would satisfy in-flight activity facilitation, as tray aspects covered three of the top ten features in the Product Design Matrix. An inflatable lumbar support would be added with the aim of providing even greater physical comfort. Both customer surveys gave good support for the inclusion of a lumbar support.

3.2.2 Webbing-Foam Hybrid Cushioning Design

With these features the team decided upon, the next step was to home in on the finer points of the seat design. One major idea that the team favored was that of having *both* webbing and foam cushioning in the same design. This idea was borne out of a desire to preserve the flotation foam in the design. This would result in having the webbed cushion only in the seat back and keeping the foam as the seat bottom. On top of keeping the flotation device, the following plus points accompanied this design:

Cost

The amount involved in replacing the entire seat with webbing would be considerable. But in this design concept, only half of the seat cushioning would be replaced with webbing, and so replacement costs would be significantly less.

Space Conserved in Horizontal Direction

With respect to space, airlines are usually more concerned with the number of seats they can place in the cabin, while passengers frequently complain about the amount of legroom they are entitled to. This would imply that space constraint in passenger aircraft is usually in terms of floorspace – in the horizontal direction – rather than headroom – vertically. A greater amount of headroom, albeit providing greater carry-on baggage capacity, would not conceivably generate more revenue for the airline as increased floorspace, as the latter scenario would increase cabin capacity. Therefore the space-saving webbing cushion would do much better in the seat back than in the seat bottom.

Gradual Introduction of a Radical Technology

With foams being such a mainstay in aircraft seat cushioning over the past decades, it is anticipated that a radical change in cushioning technology would be met with wariness and skepticism. This is especially so when the webbing cushion in use here looks and feels so different from conventional foams. It would probably be prudent to web only half the seat, leaving the foam cushion to provide the passenger with the familiar feeling at the seat bottom. As the market gets used to the idea of webbing in aircraft seating, the next phase of webbing introduction could lead to the complete webbing of seats, provided comfort tests suggest superior cushioning and support ability.

These advantages suggest that replacing just the foam seat back in current seats with webbing would be a feasible concept that makes economic sense. Safety features would not be compromised as well.

3.3 The Final Prototype

Fortunately for the team, webbing seats were already out in the office chair market. It was learnt that half a dozen webbing chairs had just been purchased not too long ago at a certain office in the Institute. The team wasted no time in placing an order for one of the *Aeron* chairs manufactured by office chair company

Herman Miller. Pictured below, this chair looked nothing like a conventional office chair – webbing seat bottom and back, adjustable armrests, lumbar support, forward-rotating seat bottom and a price of $632.

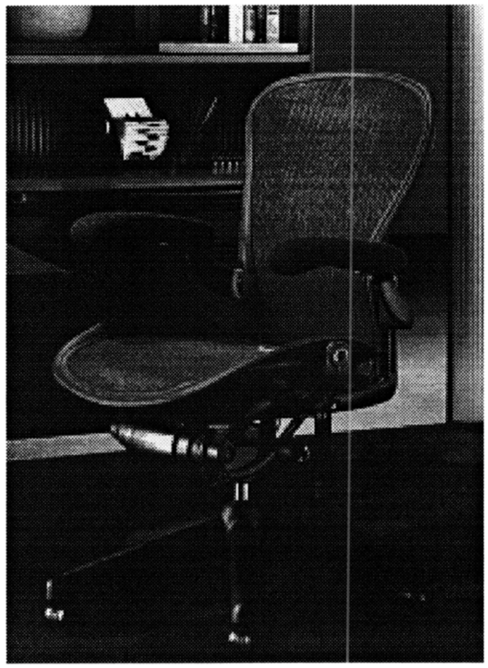


Figure 3.1: *Aeron* Chair

Touted by Herman Miller to "evenly distribute weight over the seat and back and conforms to each person's shape", the contoured webbing seat back was to be used as the prototype seat back. Developed by Herman Miller, the webbing was made from a patent pending elastomer called *Pellicle*. Herman Miller also claimed that it had the added benefit of being permeable to air, preventing body heat build-up. A close-up of the webbing material is shown below.

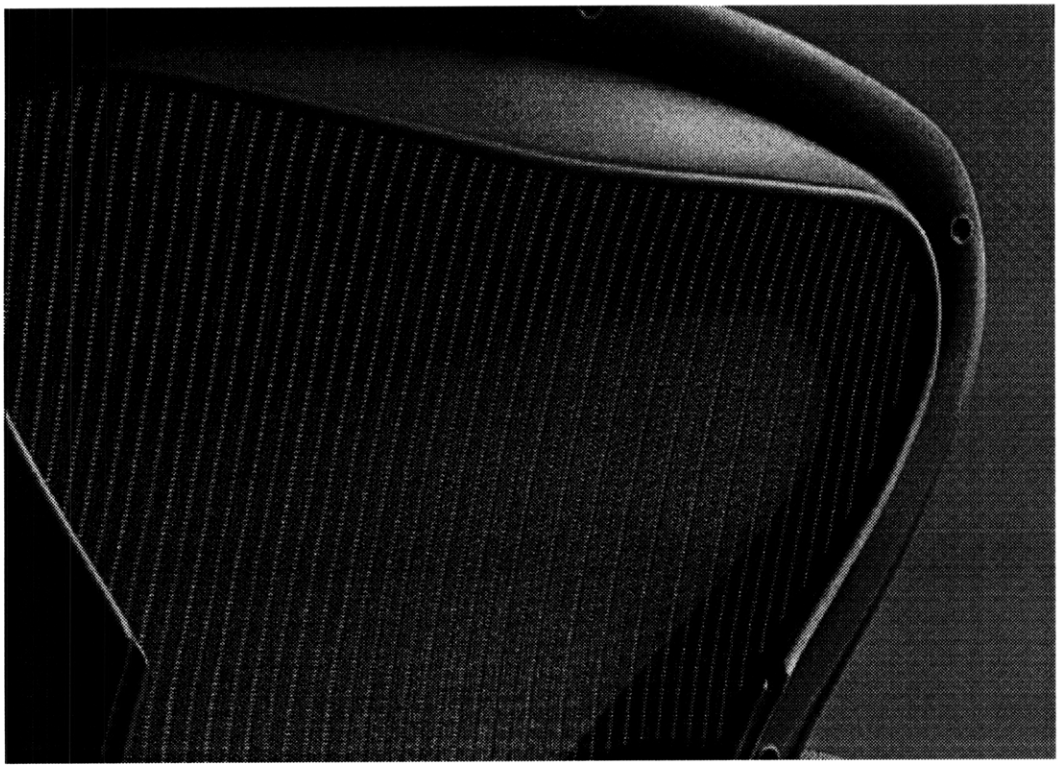


Figure 3.2: Webbing

Yet being an office chair, it was not high enough to support a typical person's head. Therefore a conventional headrest, removed from a standard baseline aircraft seat, had to be manually attached to the webbing seat back by way of clamps. The seat back itself was sawn off the *Aeron* chair and fitted into the frame of a baseline aircraft passenger seat. Thus the final prototype looks just like a conventional seat, with recline function and all, but only that the seatback is now black-colored webbing. It was not required to address the issue of adding a lumbar support to the seat, as the *Aeron* seat back came accompanied with one that was vertically adjustable. Shown below is the resulting final prototype in its front and side views.

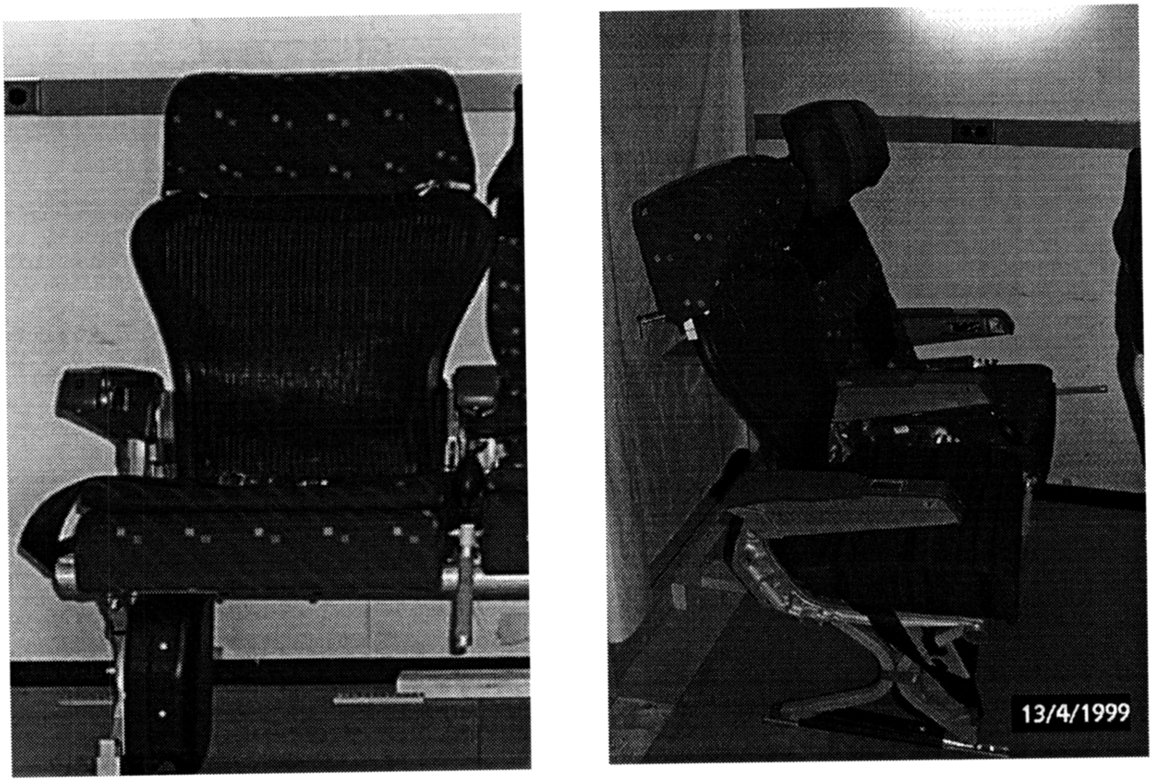


Figure 3.3: Webbing Prototype

Also a feature in the webbing prototype is a height-adjustable tray, described in greater detail in Ref. 3.

While it is realized that a personal entertainment system is an increasingly common feature of aircraft seats nowadays, this prototype was designed without consideration for the integration of one. It was noted that the personal entertainment system was ranked 48th in the Product Design Matrix. Thus it was not considered to be a sufficiently important design concept and was excluded.

Where cost is concerned, since most of the prototype seat is the same as the baseline, comparisons are made only in the cost of the respective seat backs. Figures from BE Aerospace list back structures at $433 and back cushions at $302, giving a total of $735 for the entire seat back. As mentioned above, the *Aeron* office chair retails for $632. A very rough estimate for the cost of the seat back would be to halve the retail price, making it $316. This gives approximate savings of $419 for every prototype seat over the baseline.

Chapter 4 – Seat Testing

With the prototype now in place, the next step is to test it. But it was not just a case of simply getting a person to sit on it for hours on end and have him tell the team how comfortable an experience it was. In order for objective and accurate data to be obtained, the entire experience the subject goes through must be as close to the actual flight as possible – ideally, the team would have liked to have both subject and seat in a 747 on its way to London. However the limited scale of this project ensured that all testing was done at ground level.

As such, the scenario of flight had to be artificially created. Of course, the team was more concerned about aspects that had more to do with passenger comfort, like the space between seats, lighting and the food served. Yet there were areas that could not possibly be simulated, like turbulence in flight and pressure changes. Whatever was within the means of the team to bring the testing environment as close to the actual flight situation as possible, was done. With this, the team hopes to have done enough to make the testing data as close to reality as can be.

In testing the seats, the team effectively is aiming to measure the degree of comfort that the prototype provides, compared to the baseline seat in use in typical passenger jets today. It is realized without a doubt that comfort measurement through human subject feedback is a highly subjective process, with variables too many to take into account. This calls for another form of objective testing that would complement subject opinion of the various seats. The Tekscan® Pressure Pads would fulfill this. These pads, when placed between the seated subject and the seat, allow the visualization of the pressure distribution at the interface between the subject and the seat. In this, the team hopes to find an objective method of determining passenger comfort, and also to find out just how different the seats are when scrutinized under pressure pad testing.

4.1 Testing Environment

As mentioned above, the team took all the measures it could to ensure that the testing environment resembled a flight experience as much as possible. An airline passenger seating section is functionally duplicated in a laboratory setting. A raised platform forms the floor of the environment. It is separated from the ground so that the three pairs of seats, two prototype and four baseline, can be bolted securely to it. Attachment is identical to the method used in passenger aircraft. This is made possible with the rails, bolts and nuts kindly contributed by BE Aerospace. BE also provided the team with the various dimensions of the cabin interior, such as seat pitch. The top and rear views of the testing environment are shown in the respective figures below.

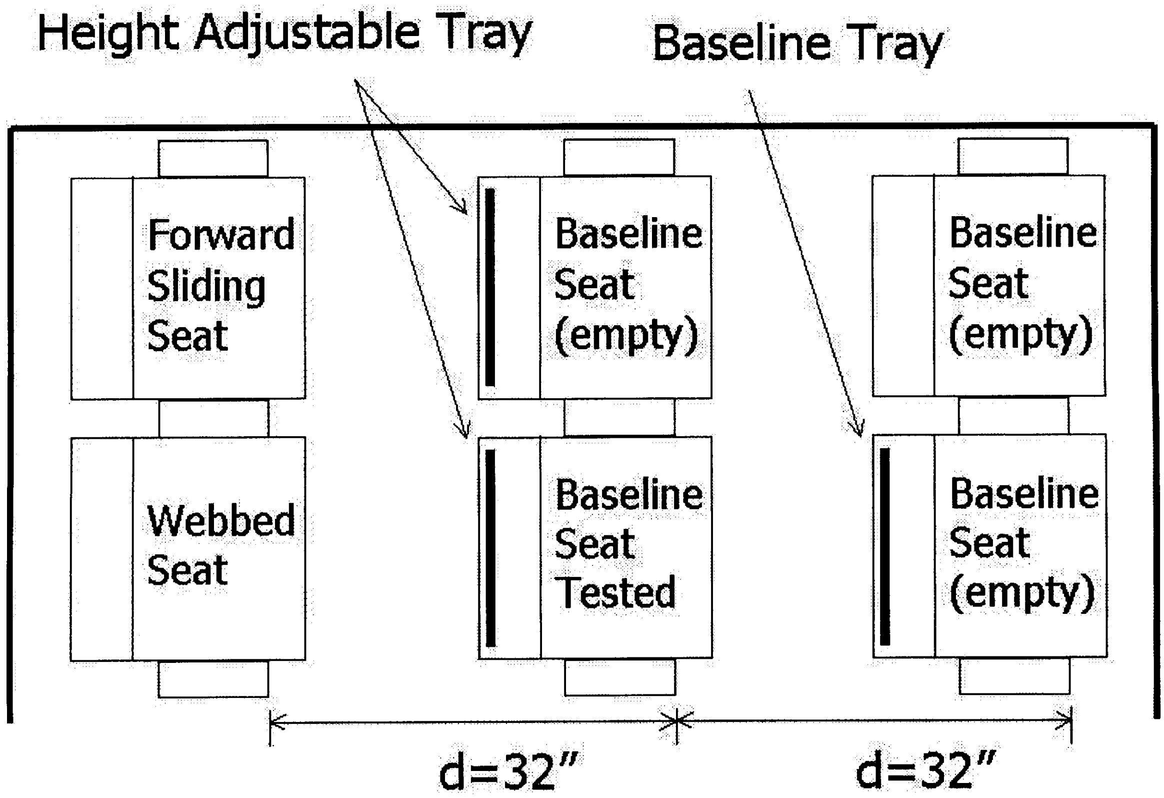


Figure 4.1: Top View

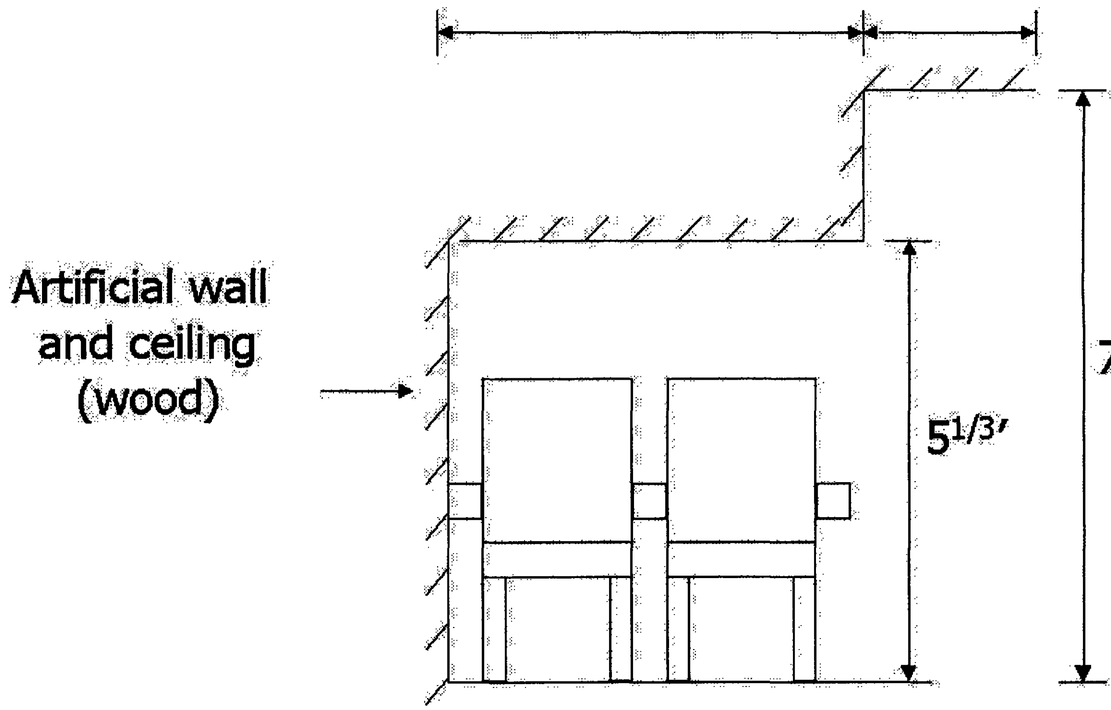


Figure 4.2: Rear View

Out of the six seats, three will be occupied by subjects, and the other three left empty. Two concept seats take up the hind row. In front of the webbing seat is the standard BE Aerospace baseline seat, on which a third subject will take his place. The front row of empty seats serves the function of restricting the space of the subject in the baseline seat. All subjects are allowed to recline as they wish, as in a flight situation, except the empty seat in front of the Forward-Sliding seat, which is left in an upright position. Height-adjustable trays are installed in front of the concept seats, with a standard tray accompanying the baseline seat.

Seat pitch is set at thirty-two inches, as advised by BE Aerospace. Directly above each seat is the simulated carry-on baggage compartment, three and a half feet wide, at five and a one-third feet above the floor. This will restrict the headroom of the test subject. At the aisle, which is one and a half feet wide, the ceiling is seven feet high.

The plywood frame of the testing environment is covered all round by pieces of white cloth to give subjects an appearance of space constriction as it is like in a real aircraft. A photograph of the testing environment is shown below:

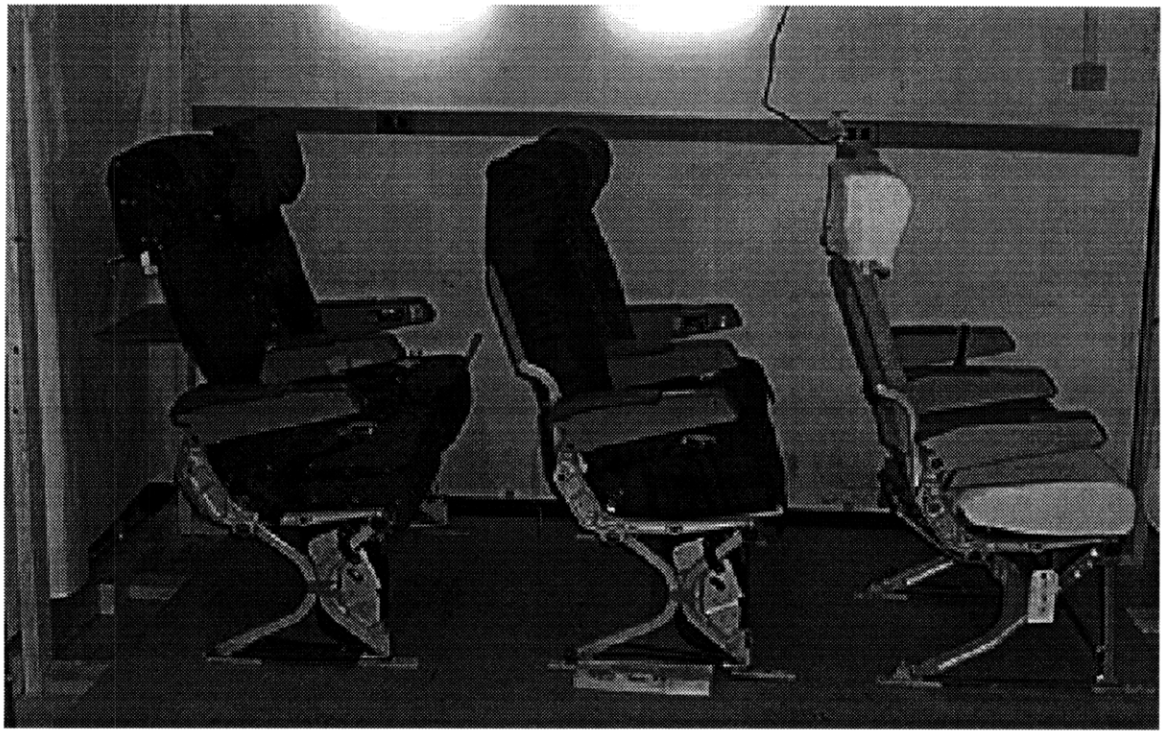


Figure 4.3: Testing Environment

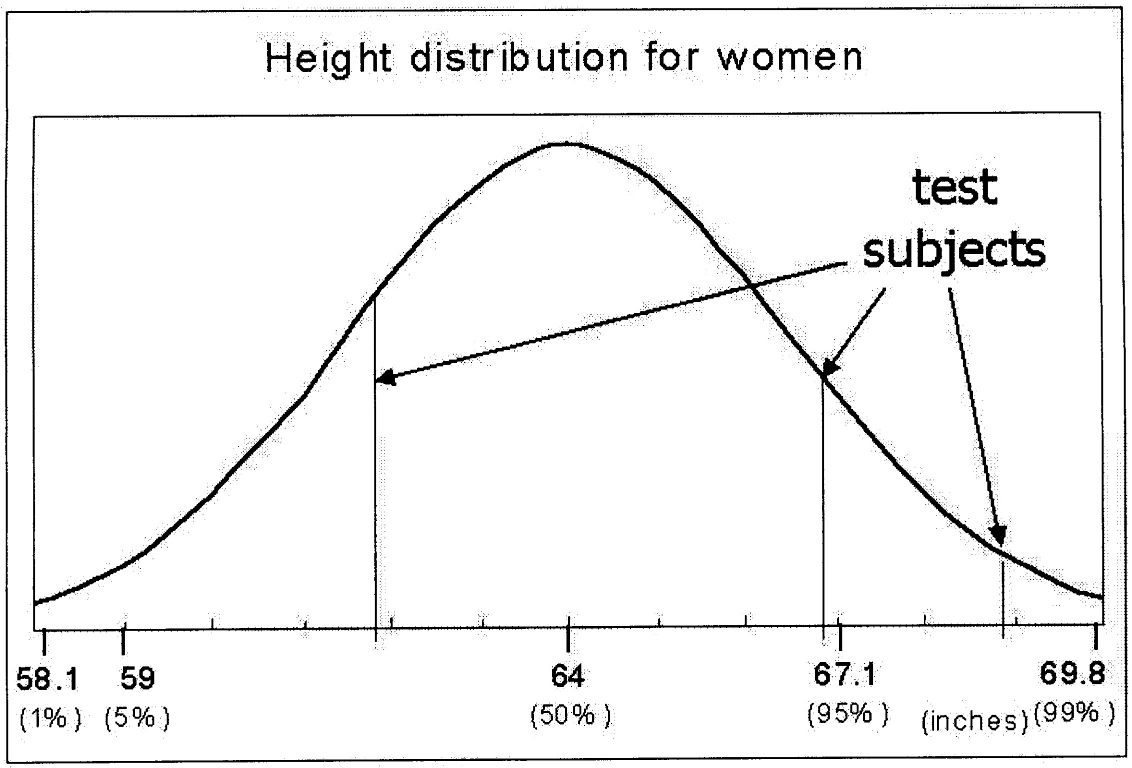
4.2 Test Subjects

The recruitment of subjects was no random process. BE Aerospace designs their tourist-class seats to fit 5th to the 95th percentile of the world human population size spectrum. It is as well the aim of the team to design the seat to fit the same range of human size. In order to do that, there must be as large a distribution of human size as possible in the group of twelve subjects who were to be tested. It was understood that testing carried out on a larger scale than just twelve subjects would lend more credibility to the results, but due to constraints in time and funding, the team would have to make do with feedback and measurements from twelve subjects.

A "Subjects For Hire" electronic mail was send to the undergraduate and graduate student community in the Aero/Astro Department. Of the twenty responses, twelve were chosen who most represented the entire range of the human size normal distribution curve. Unfortunately, the number of responses from females fell far short of those from males, and thus, out of the twelve, only three were women. The table below shows the subjects' biographical data and where they place in the human size normal distribution curve.

Subject Number	Gender	Age	Height	Weight
1	M	23	6’ 6	285
2	M	27	5’ 11 ¾	180
3	F	22	5’ 2	120
4	M	32	5’ 4	145
5	M	21	5’ 5	178
6	M	20	5’ 10	178
7	F	23	5’ 9	150
8	M	24	6’ 1	190
9	M	21	5’ 10	165
10	M	21	5’ 7	145
11	F	30	5’ 6.5	120
12	M	24	5’ 9	150

Table 4.1: Subject Biographical Data



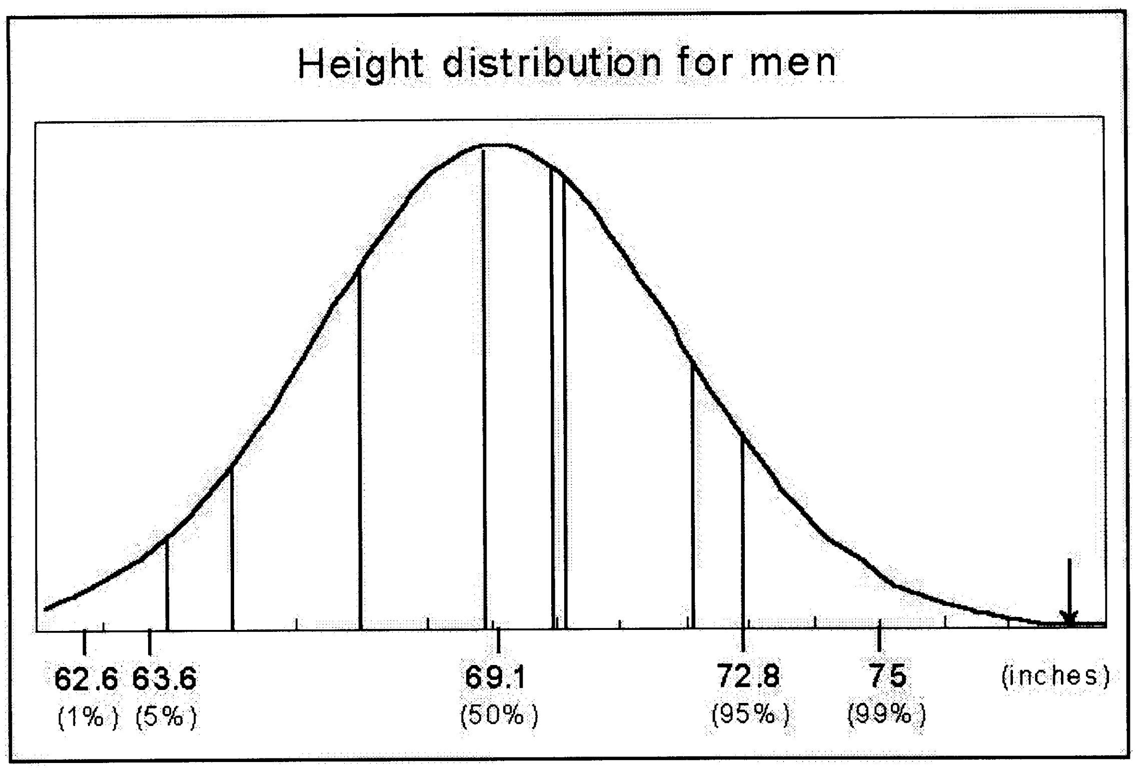


Figure 4.4: Subject Height Distribution

4.3 Testing Procedure

Designed to be similar to a typical flight, the three-hour testing process includes all of the necessary activities that a typical passenger in tourist class can expect. The following diagram gives an overview of subject activity over the three-hour testing period.

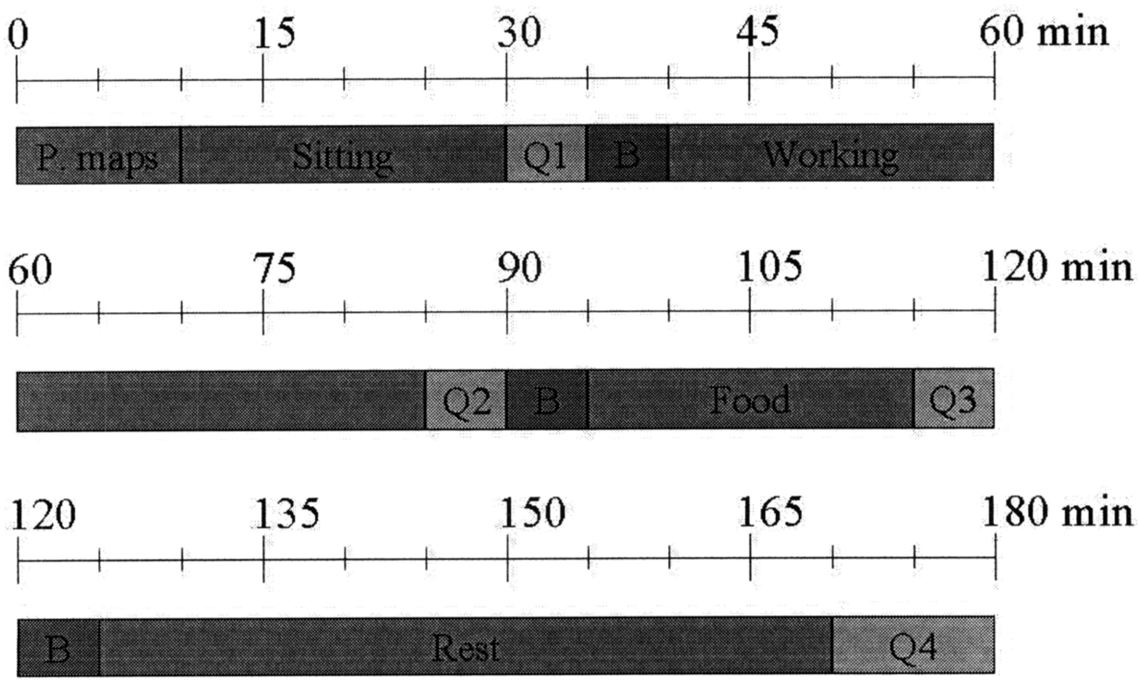


Figure 4.5: Test Timeline

All subjects follow this timeline as far as possible.

0-10min	Subject test begins by a team member taking seat pressure maps. This also simulates the takeoff phase of the flight, when the seat is in an upright position and seat belts have to be fastened.
10-30min	Seat belts can be removed and the subject is told to just sit back, recline and relax.
30-35min	First Questionnaire. Subject is asked to provide feedback on his initial level of comfort.
35-40min	First break period. Subject can get off the seat and use the restroom if he so wishes.
40-85min	Subject is asked to perform some kind of work, like working on a problem set or just simply reading.
85-90min	Second Questionnaire. Subject is asked to provide feedback on his comfort level while sitting and working.
90-95min	Second break Period.

95-115min	A simple meal, not different from those served on board, is served.
115-120min	Third Questionnaire. Subject is asked to provide feedback on his comfort level whilst eating.
120-125min	Third break period.
125-170min	Subject is asked to rest for the remainder of the testing session, taking note of areas of comfort/discomfort while resting. He can also choose to work or read if he wishes.
170-180min	Fourth Questionnaire. Subject is asked to provide feedback on his comfort level while resting/working/reading.

Table 4.2: Timeline Description

There is no specific order in which the seats are tested for each subject. This order of seat testing is done randomly to eliminate systematic error in subject comfort ratings.

4.4 Subject Questionnaires

These form the most part of the "subjective" part of seat testing, and are the main method of extracting comfort information from the testing subject. From their responses, which include both quantitative and qualitative data, comparisons between the concept seats and the BE Aerospace baseline can be made, by way of both statistics and verbal feedback.

Subjects had only to answer very fundamental questions. All four questionnaires were of the same form. Each started with the subjects having to describe his activity over the past period of time. Then the subject is supposed to rate the level of comfort for each body part, from a scale of one to five, one being very comfortable and five, very uncomfortable. Listed below are the aspects that were covered in the questionnaire.

- Overall Comfort
- Arm
- Thigh
- Leg
- Foot
- Neck
- Shoulder
- Back
- Lumbar
- Hip
- Head

The subject was then asked for general comments on the seat that were not covered in the questionnaire. Finally, if he was sitting in a prototype, he would indicate how good the seat is compared to the baseline, from a five-point scale ranging from "Much Better" to "Much Worse".

Chapter 5 – Testing Results and Analysis

From the battery of three-hour tests, the team obtained two types of data – subject responses and their pressure maps. As mentioned in the previous chapter, both kinds of data are different in nature. Subject responses are essentially subjective and contain many biases that may cause discrepancies in the way subjects judge the comfort of each seat. The pressure maps are objective in that they are the result of direct measurement – the issue of human partiality is not in question. Though this does not necessarily mean that pressure maps would absolutely outdo human responses in comfort testing and measurement. While pressure maps give a picture of comfort from a single particular point of view, human responses give, albeit subjectively, a more complete outlook of comfort. They can tell, in definite terms, whether or not a seat is providing comfort to a *human being*. Moreover, with testing in numbers, the level of subjectivity inherently involved in human subject responses can even be reduced to an acceptable level, enough for results to be conclusive.

What the team tries to do with these two types of data is, not only to draw conclusions directly from each, but also to relate both to each other to come up with even stronger conclusions. It is believed that there is a correlation between regions of variable pressure human body surface and the comfort level sensed by the human. Thus these two categories of subject data are equally important for the team to make conclusive remarks about the concept seats and the way they compare with the baseline seat.

5.1 Subject Responses

The entire catalogue of subject responses for the webbing and baseline seats can be found in Appendix 1 and 2 respectively.

5.1.1 General Results

Averaging all the scores submitted by the subjects over the four questionnaires, it is found that the subjects rate the webbing seat higher than the baseline for all thirteen seat categories, from Overall Comfort to Comfort with Tray.

When asked to compare the webbing seat directly to the baseline seat, two rated it "Much Better" than the baseline seat, seven rated it "Better", one rated it between "Better" and "Comparable", and one each for the "Comparable" and "Worse" categories. A total of ten out of the twelve subjects rated it more comfortable than the BE Aerospace baseline seat.

In terms of overall level of discomfort, the average score obtained by the webbing seat was a 2.1, compared to a 2.8 for the baseline. Readers should take note that subjects were rating comfort on a scale from one to five, one being "Very Comfortable" and five, "Very Uncomfortable".

5.1.2 Comparison of Seat Comfort Aspects

Although it is already known that the webbing seat tops the baseline seat in all of the seat aspects, one cannot be sure that the difference between the ratings given for each seat is large enough to be considered significant. Small differences could always be caused by random factors that have no notable bearing on the comfort of the seat. Therefore, a test is required to determine whether or not the difference in ratings is sufficiently significant. The t-test, described in Appendix 3, is a very commonly used statistical test to measure significant differences. With this test, one is able to declare significant difference between two values with a certain degree of confidence, while taking sample size into account. The t-test, in this case, is used to state whether certain comfort aspects of the webbing seat is significantly better than the baseline, as related by the subjects.

A significant difference in subject rating is defined as one with 90% confidence or above.

Questionnaire 1

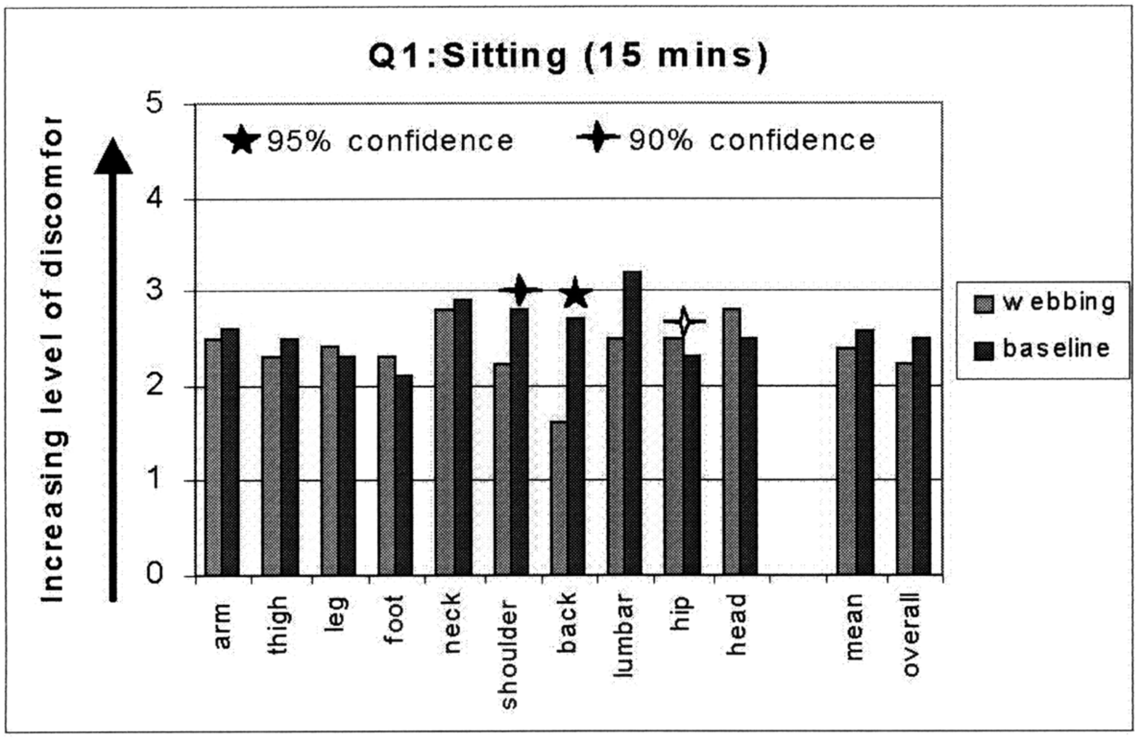
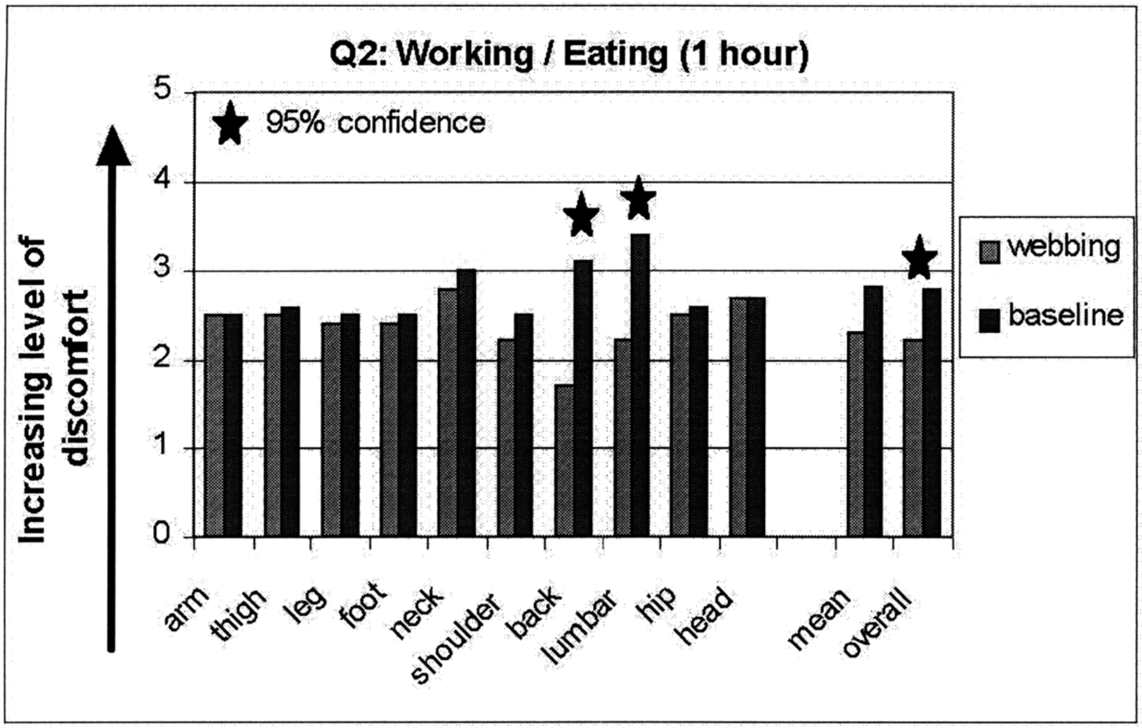


Figure 5.1: Q1 Comparison

After just 15 minutes, the effect that the webbed seat back had on back comfort was apparent. Subjects rated back comfort for the webbing seat at an average of 1.5 compared to 2.5 for the baseline. This, according to the t-test, is a significant difference with a 99.5% confidence level. Shoulder comfort was also rated significantly higher with a 90% confidence, while the hip was deemed less comfortable.

This being the first questionnaire, subjects only had about 15 minutes on the respective seats, and so the difference between the comfort levels of the two seat models would not be very apparent. More discriminating results are expected as testing continues into the latter stages, as muscle fatigue sets in.

Questionnaire 2



<u>**Figure 5.2: Q2 Comparison**</u>

After an hour, back comfort was still significantly better in the webbing seat with 99.5% confidence. Lumbar comfort also made a difference by this time, webbing bettering the baseline seat with 95% confidence. Also notable was the overall comfort being significantly higher for the webbing seat.

Questionnaire 3

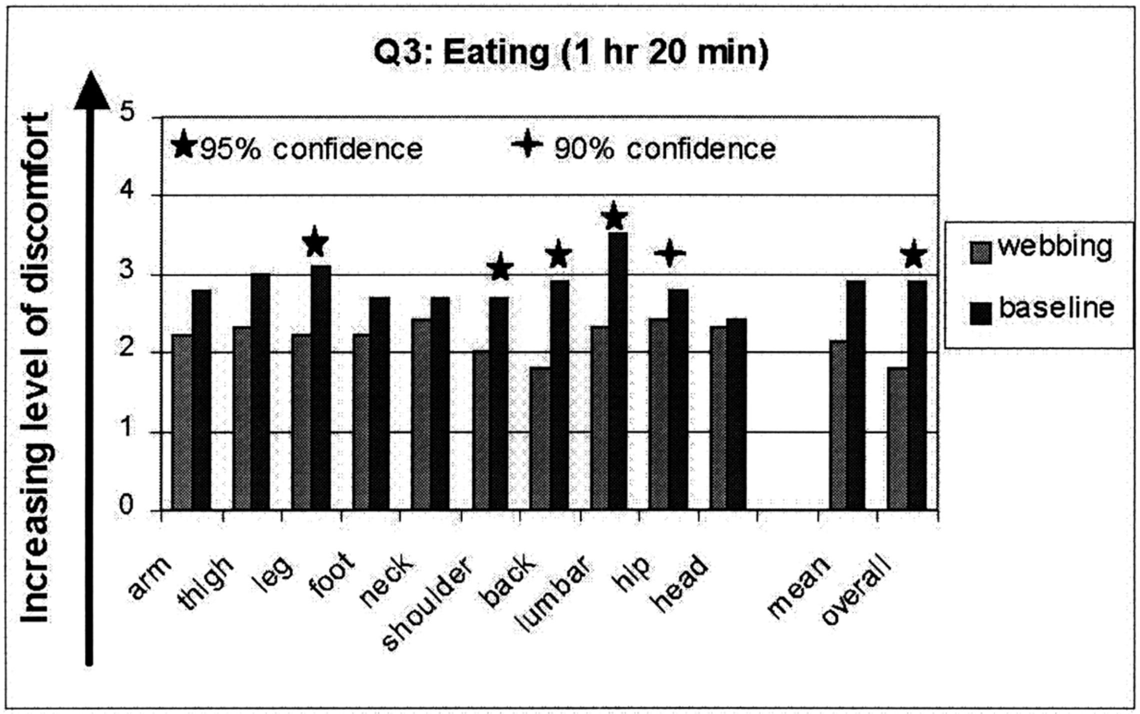


Figure 5.3: Q3 Comparison

The trends in the above graph seem to suggest two things; either the webbing seat facilitates the act of eating much better than the baseline, or the difference between the seats is telling over time. Back, lumbar and overall comfort maintained significant differences over the baseline. But aspects like leg, shoulder and hip, which one would recall was less comfortable in the webbing in Questionnaire 1, are beginning to show the disparity between the two seats. As mentioned above, the superiority of a seat, if it exists, is told to a greater extent after a considerable period of time.

Questionnaire 4

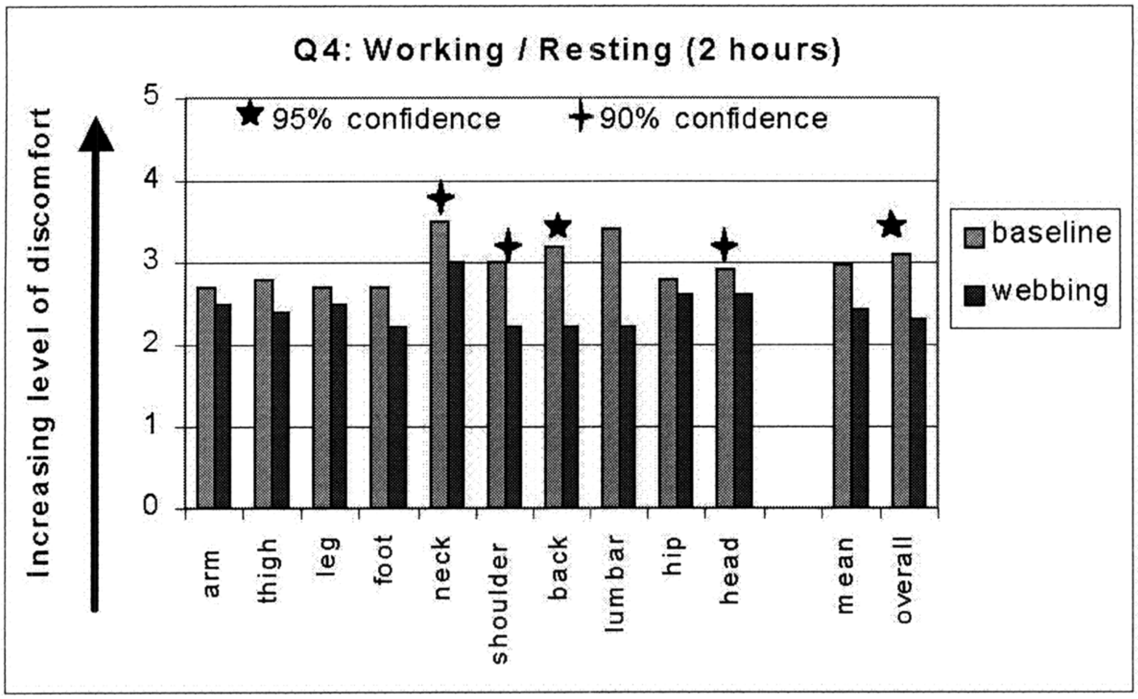


Figure 5.4: Q4 Comparison

Towards the end of the experiment, four aspects remain significantly more comfortable in the webbing. Other than the previously mentioned back and shoulder, neck and head comfort also come in. Overall comfort remains significantly better in the webbing as well.

Overall Comparisons

It should be apparent by now that subject responses strongly suggest a significantly greater degree of back comfort in the webbing seat compared to the baseline. In all four questionnaires, the webbing seat was rated significantly higher in this aspect than the baseline with a confidence of at least 97.5 %. This is compelling evidence to suggest that a webbed seat back is good for the back of the passenger.

Overall and shoulder comfort aspects were also rated significantly higher in the webbing seat for three out of the four questionnaires. This points, to a certain extent, that webbing provides good comfort for the shoulder and overall as well.

5.2 Pressure Pads

The Department purchased a pressure pad system from Tekscan for the purpose of this project. And to the department's credit, this has proved to be a most useful acquisition for the team. This is because having such a piece of advanced technology to test and verify subject responses lends more credibility to the testing, adding more value to this project.

Although the technology behind the pressure pads is highly advanced and complex, reading the maps is quite an intuitive process that does not require much effort. A pressure map is generally a color map that depicts areas of high pressure and low, with the brighter colors describing the high pressure regions and the darker colors showing the low pressure regions. Red areas would thus indicate those of the highest pressure and dark blue regions, lowest. A pressure map is versatile in the sense that one is able to calibrate the amount of pressure that corresponds to the color coding, ensuring that the level of contrast in the pressure map is always constant.

Of course, when using the word "objective" to describe the pressure pad method of comfort measurement, it is only in relative terms with reference to the human subject responses. The way to read comfort in a pressure map is still really open to opinion and the project team realizes that. Yet the team has found a knowledgeable source in the website of Herman Miller, makers of the *Aeron* chair used in prototype construction. The way Herman Miller interprets pressure maps, and how a pressure map of a person in comfort should look like, is described in detail in Appendix 4.

5.2.1 Pressure Map Analysis

So having decided on an approach to analyzing pressure maps, the focus will now be on the subjects. In line with the project objective of having the seat fit the widest range of human size possible, the focus now turns to the extremes and the median in human size available in our sample of twelve subjects. They are subjects #3, #9 and #8, who are the smallest-, largest- and median- sized ones out of the twelve. Their biographical data and comfort responses are found together with those of the other nine in Appendices 1 and 2.

Moreover, it is observed there is not much difference in the maps between the recline and the upright configuration. As such, since most passengers recline their seats in flight, analysis would be concentrated on pressure maps for the reclined seat. These pressure maps would be related with subject responses in Questionnaire 4. This is because the level of comfort that the subject feels towards the end of the experiment is a better indication of the performance of the seat, since the difference in comfort levels tend to magnify over time.

Subject #3

The pressure maps for Subject #3 in the baseline and webbing seats, in the state of recline, are as shown in Figure 5.5.

This subject did not seem to be very comfortable on this seat, as seen from her responses. She gave fours (equivalent to "uncomfortable") for comfort levels in the back, lumbar and hip when she was testing the webbing seat. For the baseline seat, she gave a two, two, and one respectively for those seat aspects. This is quite apparent in the pressure maps. In the baseline seat, the weight distribution of her back is evenly spread over the entire surface, with slight concentration at the shoulder blades - a good thing. Even though there was no diversion of pressure away from the spine as would be expected from a comfortable seat, it was much better than the pressure distribution shown in the webbing seat, from which one can easily tell does not fit her at all. Regions of high pressure were concentrated at the middle of her back area and especially the lumbar region, probably caused by ill placement of the lumbar support.

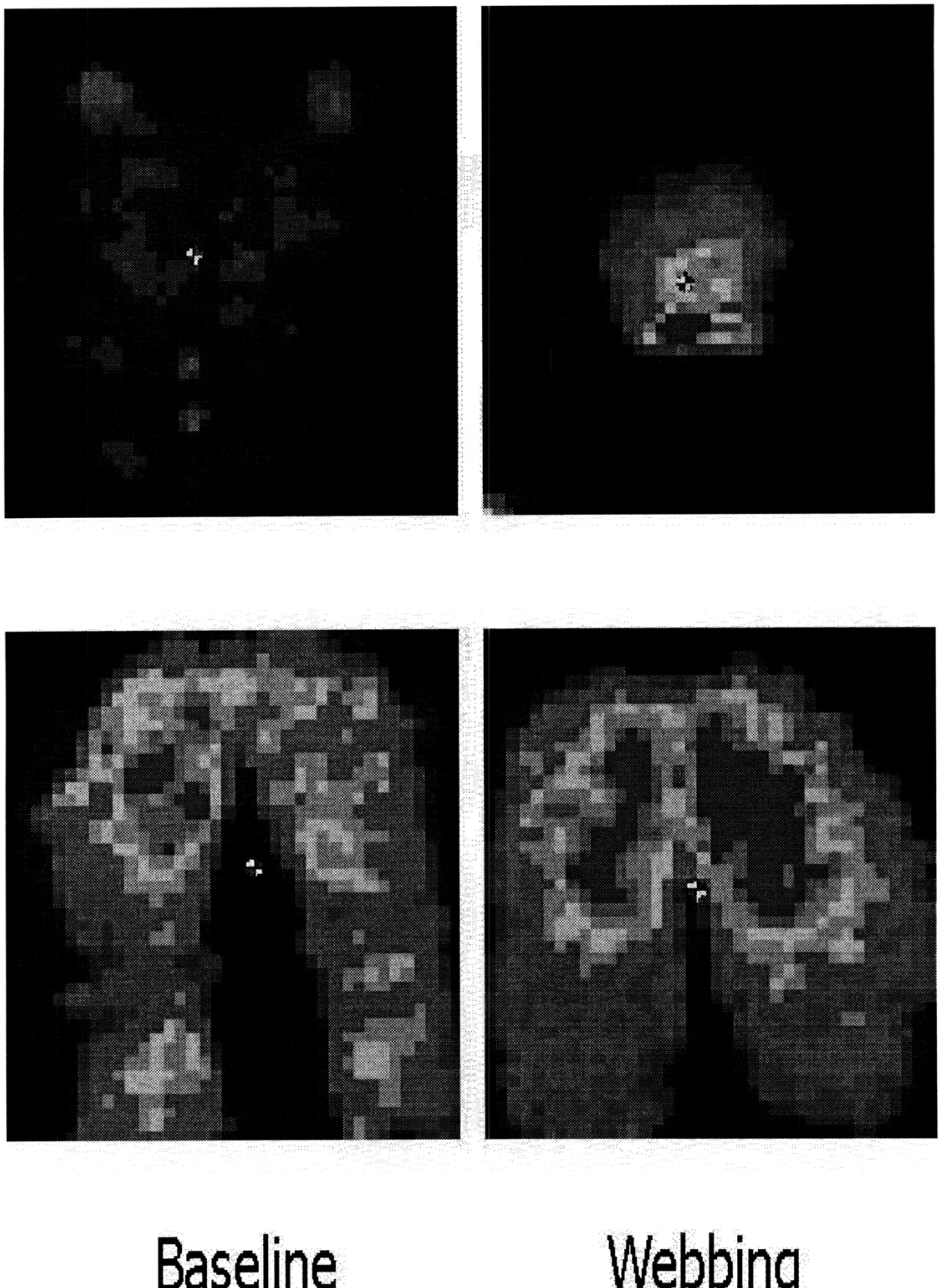


Figure 5.5: Subject #3 Pressure Maps

It is a better picture where the seat bottoms are concerned. In the webbing, the areas of pressure concentration are well placed in the sitting bones, where they should be. There is less definition of the high-pressure areas in the baseline seat, with areas of pressure spread out even along the thigh. Subject #3 nevertheless rated the baseline seat superior for most of the seat aspects. But interestingly, she assigned a two in overall comfort for both concepts.

Subject #9

This is the median-sized subject and his pressure maps are as shown in Figure 5.6.

Judging by his responses, the webbing seat fared better for this subject. He generally gave twos and threes for the webbing comfort aspects and threes and fours for the baseline seat. In particular, for the back and shoulders, the webbing seat received twos for both, while the baseline seat had a three and a four respectively, even when the subject commented that his "neck and shoulders felt good" in the baseline. This is reflected in the well-defined areas of high pressure in the webbing map, and the lack of it in the baseline. A careful observer would be able to see that pressure is kept away from the spine in the webbing seat, whereas in the baseline, there are patches of green spilling into the middle of the subject's back.

For the seat bottom, the situation is the same, where there is good concentration of pressure in the sitting bones, and lack of high pressure in the tailbone. It is not the same for the baseline seat, in which a large region of high pressure spotted just next to the middle of the passenger hip area. Over a long period of time, this would translate into stress on the bottom of the subject's spine.

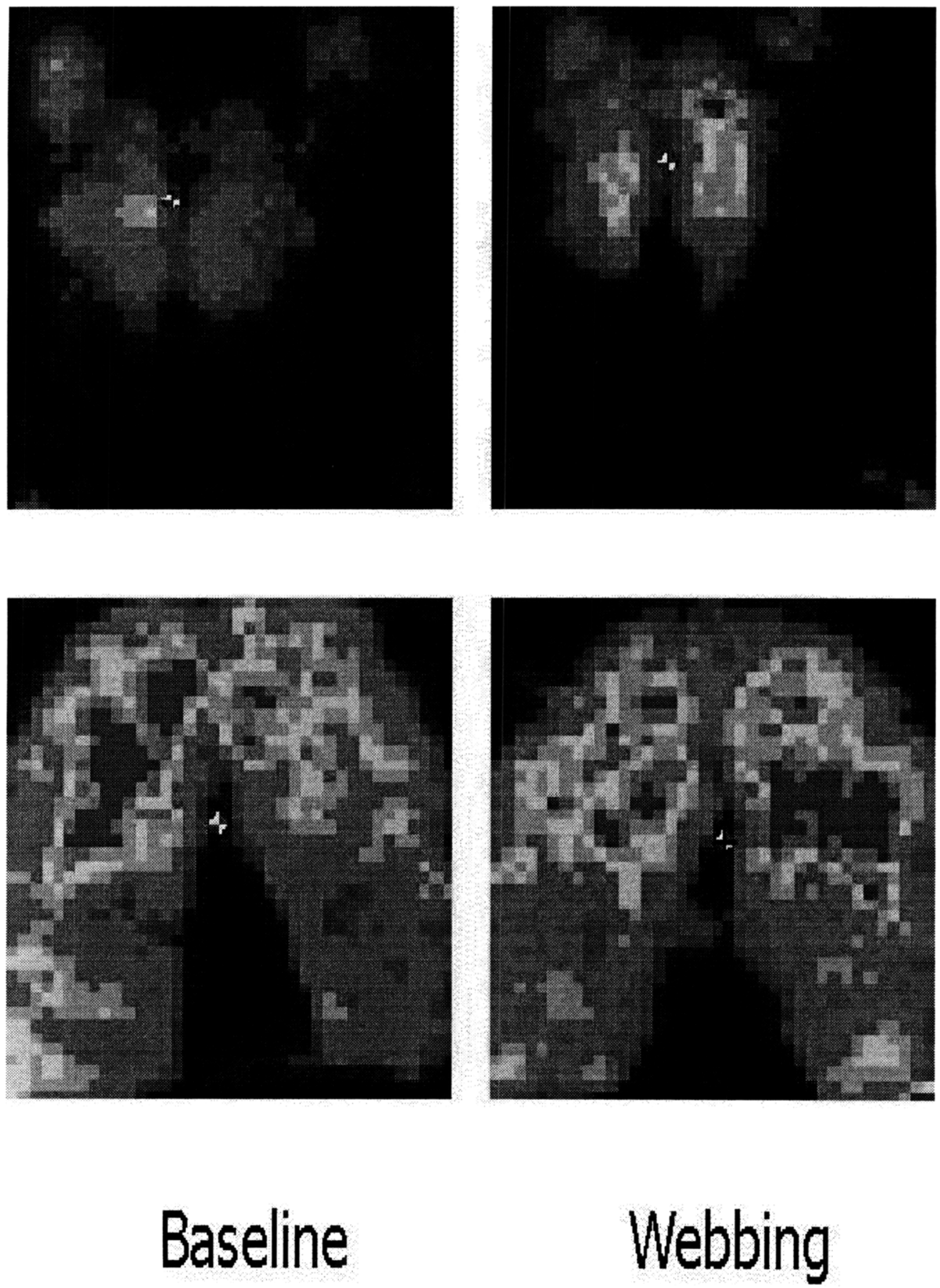


Figure 5.6: Subject #9 Pressure Maps

Subject #8

The pressure map trends are just as favorable in the largest-sized subject (Figure 5.7). For the shoulder, back and lumbar, he gave a five, four and five respectively for the baseline, and two, two, and three for the webbed seat. As for the seat back, this subject's pressure configuration is not entirely different from the one for Subject #9 – with the exception of the high-pressure regions appearing in a lower region around the lumbar. But the valley of low pressure along the spine is still very much noticeable compared to the baseline map, and this is reflected in the subject response.

For the webbing seat bottom, the high pressure concentration in the sitting bones is present, as it should be in a comfortable seat, while it is more diffuse in the baseline, even affecting the spine. The subject gave a five for baseline thigh comfort, compared to a three for the webbing. This is apparent from the areas of high pressure at the bottom of the baseline pressure map, a highly possible source of discomfort. This is not seen in the webbing map and thus places the seat in a better light.

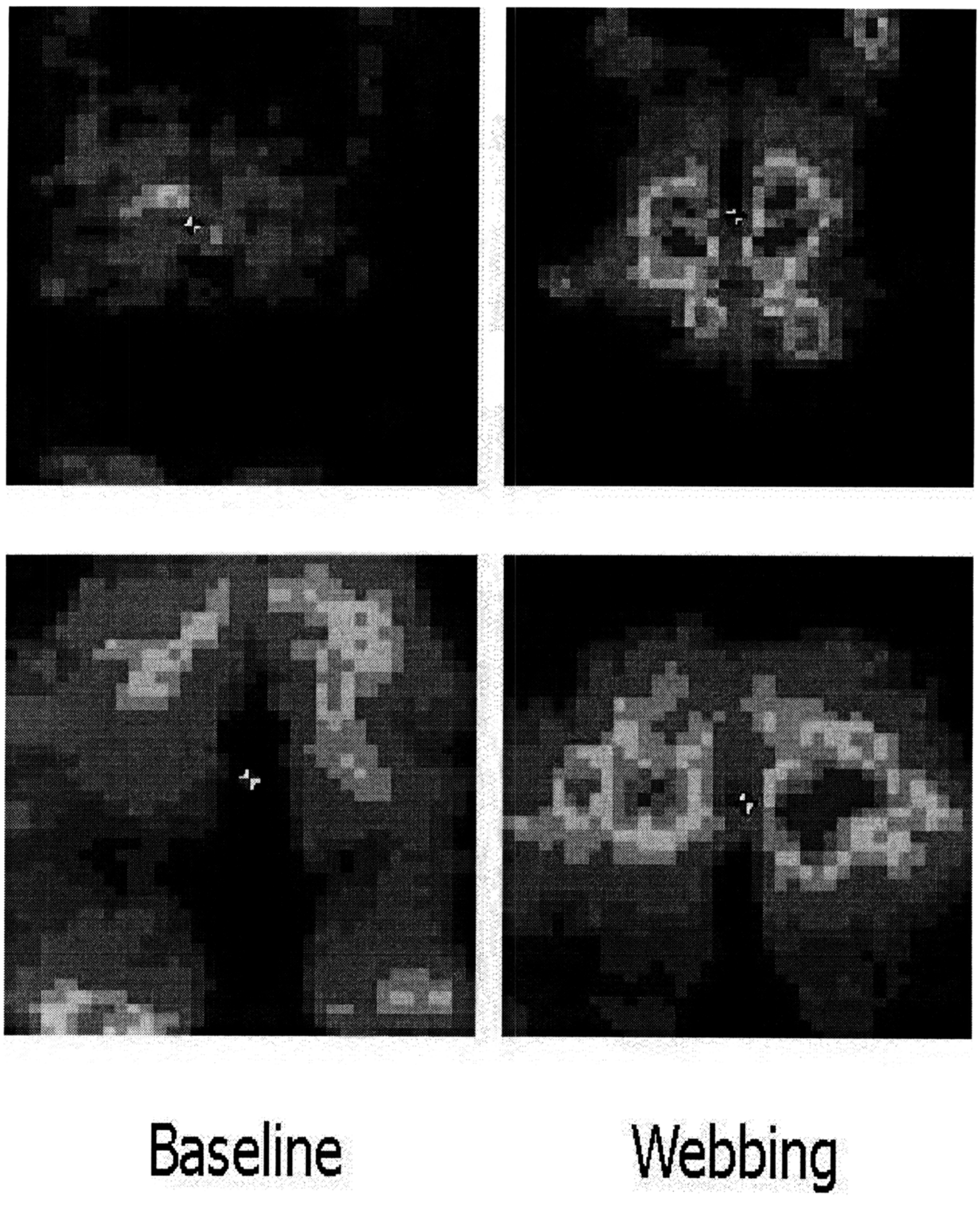


Figure 5.7: Subject #8 Pressure Maps

Other subjects

The pressure maps for the other subjects in the test are available in Appendix 5. These maps, like the ones shown in this chapter, are for the recline position.

5.3 Results Overview

It can be seen that general trends in overall comfort are followed by both sets of experimental results. In other words, it can be read from a pressure map whether or not the seat is generally more comfortable or less.

But whether or not they correspond, both sets of data suggest one thing – that the webbed seat provides a greater level of comfort than the baseline seat. From the subject feedback, overall comfort is superior, especially over a longer period of time. In particular, the webbed seat is apparently superior to the baseline seat in terms of the comfort it provides to the passenger's back. Pressure map data shows agreement, in that much of the pressure is diverted away from the passengers' spine, mostly to the shoulder blades and the sitting bones.

From these data, the team is very convinced that a seat with its back cushion formed from webbing would offer more in terms of comfort to the passenger, and especially to his back comfort.

Chapter 6 – Conclusion

Work on this thesis enabled the team to explore the avenues through which passenger aircraft seats of today can be improved. The webbed cushioning concept proved to be a very viable method of achieving this. Its many favorable properties, most of all its minimal weight and volume characteristics, enabled it to stand out as a concept for seat improvement. This is also because conventional foam cushions have numerous associated drawbacks, and many of these drawbacks are covered by the webbed cushioning concept.

With these advantages that it has over the foam cushion seat, one would think that the webbed seat would only need to provide a level of comfort comparable to the foam cushion seat to confirm its superiority. Yet with extensive tests that not only gather feedback from human subjects but also takes pressure measurement into account, the team has successfully determined that the webbed seat is more comfortable than the foam cushion seat. From customer surveys, it has been found that the two areas of passenger seating that most acutely requires improvement are those of passenger space and back support. With its zero-thickness trait, the space problem is tackled, and with results from subject comfort ratings and pressure maps, one can confidently say that back comfort is fulfilled as well.

Though one must take note that these results were achieved with only the seat back webbed, *not* the entire seat. This suggests better results for a fully webbed seat, plus more of the benefits that arrive when the seat bottom is replaced by another webbed surface. And though this is so, the team believes a hybrid-cushion design will be able to make a sufficiently significant improvement over the seats that are in use today, and work on this thesis strongly suggests that it will.

As such, it is believed that the project objective of "finding scientific, creative and innovative means to improve passenger comfort in tourist-class seats during long-haul flights" is fulfilled with this webbing design. Not only does it satisfy passenger comfort, the team is convinced that this design would also achieve industry requirements, generating more profit for airlines and the various manufacturers in the long run. Yet how many of the benefits would reach the tourist-class customer, is very much dependent on industry. For it is the airlines who will decide how many of these seats are going to make it into the tourist-class section, how dense seating is going to be. They could take the consumer-oriented decision and decide to freeze the number of seats, making it more spacious for each passenger. Or to take the profit-oriented approach, using the extra space that is freed up by the webbing to add more seats into the cabin, leaving the passenger with the amount of space that he started out with. This is really up to the airline and the aircraft makers. But perhaps they should note that with this design, savings from fuel and maintenance would already yield an increased profit margin. Long-haul passengers definitely deserve the greater degree of comfort that this seat design would accord them.

Appendix 1 – Subject Responses for Webbing Seat

	Questions											
Subject number	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*Comments*
1*	2	3	3	3	3	2	2	1	2	3	2	reclined bad for legs and esp knees - back support comfy
2	2	3	2	2	2	3	1	1	4	2	2	I have an easily aggrevatible lower back, and although I like the springiness of the tight mesh, the lumbar support is WAY TOO LUMPY
3	3	1	1	1	1	1	1	2	4	2	3	
4	3	4	3	4	3	2	2	2	2	2	2	arm rest low, face of arm rest should be softer and larger
5*	2	3	3	2	3	4	2	1	2	3	4	back support excellent. Feels really good for middle back
6	2	2	3	2	1	4	2	1	3	3	4	head rest too far from person (should be moved forward) - too much pressure on the lumbar area (nothing more than a slight discomfort) - hip/buttocks area too flat (more comfortable with deeper thigh/butt indentions ?)
7*	1	1	1	1	1	1	1	1	1	1	2	webbed back offers increased support to upper back and shoulders - head rest not as comfy as lumbar seat head rest, too low
8	3	4	3	3	3	4	4	2	4	3	2	webbed seat a little hard at beginning, but quite comfy; No lumbar support: hurts; Head rest comfy but too small; Should be a neck support; (if sitting straight, comfy, but if slouched, neck not supported anymore); Arm rests not wide enough and not comfy at all; hurts shoulders
9	2	3	2	3	3	2	1	1	3	3	2	webbed backing very comfortable
10*	2	2	2	2	2	3	3	1	1	2	3	lumbar supp is fine but head and neck have nothing to rest on unless slouched
11	2	3	3	4	4	3	3	2	3	3	3	
12*	1	2	2	2	2	3	3	2	2	3	3	

Ave	2.1	2.6	2.3	2.4	2.3	2.7	2.1	1.4	2.6	2.5	2.7

Webbing Questionnaire 1

		Questions													
Subject number	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*Comments*
1*	reading (35mn), resting (10mn)	2	4	4	3	4	2	2	1	1	3	2	3		very little room to lean forward to work - hard to lean chair back to be comfy
2	reading (10mn), chat (20mn), rest (5mn)	2	3	2	2	1	4	2	1	5	1	3	2	1	lumbar "rock" should be removed or softened - height adjustment tray increased comfort and ease of filling out this form
3	slept (45mn)	1	1	1	1	1	1	2	2	2	1	4	4	1	a bit distracted to have knee up against front seat
4	reading (15mn)	2	2	3	2	2	2	2	1	2	3	2	1	2	tray okay fot thigh, but looks likely to break if heavy stuff on it
5*	talking, nap, pulled out tray table	3	2	3	3	3	4	1	1	1	2	4	3	4	neck support not adjust so hits head and not neck. Adjusting tray is very difficult
6	working (45mn)	3	3	4	4	3	2	1	1	1	4	2	2	2	not enough arm & leg space - interfernce of room with the second passenger
7*	reading, working	1	1	1	1	1	2	1	2	2	1	2	3	1	decrease in head/neck comfort due to leaning forward - tray table very comfy - back a little bit uncomfy
8	working (1hour)	2	4	3	3	3	3	4	2	3	3	3	3	1	can't use head rest when working b/c leaning forward; tray very useful and comfy (don't have too lean too much so back better and arms better b/c on the tray and not on arm rests)
9	homework (40mn)	2	4	3	3	3	3	2	2	3	3	2	2	1	
10*	reading (15mn), sleeping (10mn)	2	2	2	2	2	3	2	1	2	2	2	2	2	neck support would be great
11	reading	3	3	3	3	4	3	3	2	3	3	3	2	3	no foot rest. Did not know for the tray adjustability
12*	reading (1hr)	2	2	2	2	2	3	2	2	2	3	3	1	1	pillow would be a good idea
	Average	2.1	2.6	2.6	2.4	2.4	2.7	2.0	1.5	2.3	2.4	2.7	2.3	1.7	

Webbing Questionnaire 2

	Questions													
Subject number	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*use of tray*	*comfort with tray*	*Comments*
1*	2	3	4	3	3	3	2	2	2	3	3	3	3	
2	2	1	1	2	1	4	2	2	5	2	2	3	1	
3	1	1	1	1	1	1	1	1	1	1	1	4	1	very comfortable b/c tray adjustable. (difficult to adjust)
4	2	2	2	3	3	2	2	2	3	3	2	2	2	
5*	2	3	3	2	3	2	1	1	2	3	4	3	4	neck support not adjust so hits head and not neck. Adjusting tray is very difficult
6	2	4	3	2	2	2	2	3	2	3	1	1	1	seat & tray very well suited for eating process - does not require use of head rest (for eating) - space is less of a problem when eating except for arm/elbows which still interfere heavily
7*	2	1	1	1	1	2	1	2	2	1	2	3	1	
8	2	3	3	2	2	2	3	2	3	3	2	2	1	tray helps for good position. Head rest useless
9	2	3	3	3	3	3	2	2	3	3	2	1	1	
10*	2	2	2	2	2	2	2	1	1	2	2	2	2	
11	2	3	2	3	4	3	3	2	2	2	3	3	3	
12*	1	2	3	2	2	2	2	1	2	2	4	1	1	head rest too much backwards

Ave	1.8	2.3	2.3	2.2	2.3	2.3	1.9	1.8	2.3	2.3	2.3	2.3	1.8

Webbing Questionnaire 3

		Questions											
Subject number	*Tasks*	*Overall comfort*	*arm*	*thigh*	*leg*	*foot*	*neck*	*shoulder*	*back*	*lumbar*	*hip*	*head*	*Comments*
1*	reading (45mn)	2	3	4	4	3	3	2	2	2	4	2	
2	chat (20mn), reading (20mn)	2	2	1	1	1	4	2	1	5	2	2	really like the mesh back
3	slept, talked	2	2	1	1	1	3	3	4	4	4	4	knees against seat
4	talkgin(50mn), reading(30mn)	2	2	2	3	3	2	2	2	2	2	2	
5*	relaxed and talked	2	3	3	4	3	4	2	1	2	3	4	loved that tray did not move forward when front seat was reclined
6	studying, talking (30mn), resting	2	4	3	2	2	1	2	3	2	2	1	discomfort did not increase appreciably after several hours in the seat
7*	working, talking	2	1	1	1	1	2	1	3	3	1	2	lower back and back in gen became more and more uncomfy w/ time - when front seat rec, failry comfy but a small protion of table area reduced
8	working (1hour)	2	3	4	3	2	3	3	2	2	2	3	tray helps for good position. But too much pressure on thighs
9	homework (1h)	2	3	3	3	3	3	2	2	3	3	3	
10*	studying (1hour)	2	2	2	2	2	3	2	1	1	2	2	
11	reading, resting, thunb-doodling	3	3	2	3	4	3	3	2	2	2	3	less space, less comfy
12*	reading (2hr)	2	2	3	3	2	3	2	2	4	3	3	okay w/ front seat rec. enough space - using inflatable lumb supp and adj head rest would be perfect

Average	2.1	2.5	2.4	2.5	2.3	2.8	2.2	2.1	2.7	2.5	2.6

Webbing Questionnaire 4

Subject number	Comments: General	Compare with... Much better	Better	Comparable	Worse	Much worse
1*	very comfy back. Much better than others. Adj tray is very good as well	1				
2	mesh pretty cool, probably great weight savings, supports upper back very well - lumbar support extremely awkward & uncomfortable, especially with my bad lower back		0.5	0.5		
3	really liked tray. No head support so neck and shoulders sore. Arm rests and cushion good. Mesh seat comfortable, although lacked lumbar and back support (lumbar supp uncomfy and hard)			1		
4	overall comfort good. Arm rest too hard, low, narrow				1	
5*	more comfortable for back, but lacks neack area. Hard to sleep because of that. Knees hurt after a while	1				
6	better than a standard tourist class seat - fewer "pressure points" of discomfort - very little variation in comfort level over time - head rest could have been moved closer to the head so it could be used more easily - lumbar area felt excess pressure on it at the beginning but then it passed		1			
7*	great shoulder support - adj head rest preferable - adj tray is a plus - lower back supp uncomfy w/ time: lumbar support would be a nice combo with webbed backing		1			
8	tray provides bettre position. Back support much bettre. Head rest too far for working. Arm rest bad and seat too narrow (but height of tray also helps for this). Fell less tired than with a regular seat. Lack of lumbar support not a pb when working		1			
9	more comfortable than other airline seats		1			
10*	great for back and lumabr, but really lacks neck/head rest - therefore great for working/eating but not for sleeping		1			
11	generally better than reg seats, except for foot b/c no foot rest		1			
12*	very comfy except for lumbar supp (hard) - head rest too much backwards - pillow would be welcome		1			

Webbing Final Comments

Appendix 2 – Subject Responses for Baseline Seat

	Questions											
Subject number	Overall comfort	arm	thigh	leg	foot	neck	shoulder	back	lumbar	hip	head	Comments
1	3	2	4	3	2	4	5	4	3	4	3	head rest at shoulder level
2	2	2	1	1	1	3	2	2	3	1	2	very familiat feel. Diff to make first impressions. Seat back a little too firm
3	2	1	1	1	1	1	1	3	4	1	2	very comfy - head rest in a very nice position/location
4	2	2	2	3	2	2	2	1	1	1	2	front edge of seat a little bit too hard. Should be softer than center
5	3	4	4	2	1	3	4	3	3	3	2	
6	2	2	2	2	1	3	1	2	2	2	1	neck supp not adequate - shoulder supp much better in this chair than in fs - overall comfort close to 1.8 - no noticeable pressure point in discomfort
7	2	2	1	1	1	1	2	2	3	1	1	surprisingly, feel very comfy in this seat (attributing to early comfort familiarity w/ this type of seat). Immediately after sitting, felt as if was actually sitting in an aircraft. Nice lteg/foot room. Noticeable difference in back support dut to lack of ulmbar support
8	4	5	3	4	3	4	5	3	5	3	4	
9	2	3	3	3	3	3	2	2	3	3	2	
10	2	2	2	2	3	2	2	2	3	2	2	
11	3	3	3	3	2	4	4	3	3	2	5	
12	2	3	3	2	3	3	3	3	3	3	2	
Av	2.4	2.6	2.4	2.3	1.9	2.8	2.8	2.5	3.0	2.2	2.3	

Baseline Questionnaire 1

		Questions													
Subject number	Tasks	Overall comfort	arm	thigh	leg	foot	neck	shoulder	back	lumbar	hip	head	use of tray	comfort with tray	Comments
1	reading (20mn) resting (25mn)	3	2	3	4	3	5	4	4	3	3	4	5	4	tray table hard to use with any leg comfort
2	read (45mn). Seat up, tray down	2	2	1	1	1	4	2	2	3	2	2	1	4	tray table too low
3	slept and just sat (45mn)	2	1	1	1	1	1	1	2	3	1	1	5	5	tray too low, can't cross legs or maneuver at all when down
4	sleeping (30mn)	3	2	2	2	2	4	3	2	2	2	5	2	3	
5	talking / reading / relax	3	3	3	3	3	2	2	4	4	4	3	2	4	
6	rested/slept (45mn)	2	2	2	1	2	2	1	2	3	3	1	1	1	with time, lower back (lumbar) got sore
7	homework	3	2	3	2	2	1	1	2	3	1	1	1	4	overall comfort went down due to tray table along w/ thighs and legs. Tray uncomfy: sat low on and put pressure on thighs. Lower back support decreasing
8	working (55mn)	4	5	4	4	3	3	4	5	5	3	3	4	5	
9	reading (30mn)	3	3	3	3	3	3	3	3	3	3	3	3	4	
10	resting (30mn)	2	2	3	2	3	2	2	3	3	2	2	2	3	
11	sleepng(15mn), reading(45mn)	3	3	3	3	3	4	3	3	3	3	4	3	5	
12	rested	2	3	3	2	2	3	3	3	4	3	3	3	3	
	Average	2.7	2.5	2.6	2.3	2.3	2.8	2.4	2.9	3.3	2.5	2.7	2.7	3.8	

Baseline Questionnaire 2

Subject number	Questions: Overall comfort	arm	thigh	leg	foot	neck	shoulder	back	lumbar	hip	head	use of tray	comfort with tray	Comments
1	3	3	3	4	4	3	4	3	4	3	3	2	4	legs cramped being under the tray table especially feet and ankles
2	3	3	1	1	1	3	2	3	4	2	2	1	3	tray ok but a but low. Tall person and have to slouch way over to reach food. Very little maneuverability ofr legs beneath tray. Very tight space to eat in. hard surface under arms and elbows cause discomfort
3	2	3	4	4	3	1	1	2	2	2	3	5	5	tray very low - eating diff b/c tray so low (like eating from your lap) - otherwise seat comfy for sitting upright
4	2	2	2	2	2	2	2	2	2	2	2	2	3	tray little bit too low
5	4	4	4	3	3	3	3	3	3	3	3	2	2	not too bad for a coach class
6	2	2	2	2	1	2	2	4	3	3	1	1	1	back hurts even more while eating and leaning over - front seat rec was in the way significantly for any activity, esp eating - overall comfort 2 b/c tray is 1 but chair irself closer to 3
7	3	2	3	3	3	2	2	2	4	2	2	1	4	miss lumbar support and moveable tray. Believe decrease in head/shoulder rating due to leaning fwd for homework. When front seat reclined, extremely cramped in this seat area
8	5	4	4	4	4	4	5	4	5	4	3	3	4	
9	2	3	3	3	3	2	2	2	3	3	2	4	4	
10	2	2	2	3	2	2	2	2	3	2	2	2	3	
11	3	2	4	4	3	3	3	3	3	4	3	4	5	
12	3	3	3	3	3	3	3	4	4	3	3	3	3	tray too low

Av	2.8	2.8	2.9	3.0	2.7	2.5	2.6	2.8	3.3	2.8	2.4	2.5	3.4

Baseline Questionnaire 3

		Questions											
Subject number	Tasks	Overall comfort	arm	thigh	leg	foot	neck	shoulder	back	lumbar	hip	head	Comments
1	reading (35mn) resting (10mn)	4	4	3	4	4	4	4	4	3	3	3	very hard to rest - uncomfortable esp. neck - no head support
2	read, seat slightly rec, tray down. Front seat fully rec	3	3	1	1	1	4	2	2	3	2	3	choice of tasks made it diff to be comfy w/ fron seat rec. very little room to read, trya too low. Arm tired having to hold paper at eye level
3	rested, sat, talked (45mn)	2	1	1	1	1	1	1	2	2	1	2	
4	sleeping (30mn), relaxing (20mn)	2	2	2	2	2	4	2	2	2	2	4	
5	talking / relaxing	3	3	2	3	4	3	3	3	3	3	4	neck very sore because head rest not adjustable
6	wrote (20mn), read (30mn)	3	2	2	1	2	3	2	3	3	2	1	front seat annoying when writing
7	homework	3	2	4	3	3	2	2	4	4	2	2	space extremely resticted w/ front seat rec. diff to have drink on table. Back achy, tray uncmofy b/c pressure on thighs
8	working (1h30)	5	3	5	4	4	5	5	4	5	3	4	tray to low
9	sleeping (1hour)	3	3	3	3	3	4	4	3	3	3	3	neck and shoulders felt good when not sleeping
10	chatting (1h)	2	2	2	3	2	3	2	3	3	2	2	
11	reading, resting (1h1/2)	3	3	3	3	2	4	3	4	4	4	4	resting: head and neck uncomfortable
12	rested	3	3	4	3	3	3	4	3	4	4	3	tray definitely too low

Average	3.0	2.6	2.7	2.6	2.6	3.3	2.8	3.1	3.3	2.6	2.9

Baseline Questionnaire 4

Subject number	Comments *General feeling*
1	alright - uncomfortable - head support too low
2	very average. Overall vey firm, making any position other than upright slightly uncomfy. Head rest at very uncomfy height. Very little side-to-side restraint for head, keeping from sleeping comfy and deeply. Tray tavle should be higher
3	fairly comfy - only complaint; tray table very diff to use and too low - headrest nice, standard but comfy
4	head support makes head uncomfy when sitting reclined
5	very average - neck support OK for short while but then quickly strains neck - arm rest : could use softer material - neck rest should be adjustable
6	pain in back/butt region and strain in neck while writing - nice shoulder supp, easiest to sleep/rest in - while other seats ratings were consistent, this one gets more uncomfy with time, a large factor for longer flights
7	started off fine. Lower back achy after eating. Tray too low, incomfy for thighs. Not enough room to operate tray table when front seat rec
8	not comfortable for lumbar, shoulders & back - really bad tray - here leg room not too bad - really tired at the end like always
9	seat comfy overall but not when sleeping
10	pretty comfy sitting up right, but when sleeping or slouhing, lack support in back and head/neck
11	leg space okay, considering time period. Bur for resting, head and neck uncomfortable
12	at beginning, seemed very comfy but no lumbar support, tray too low and was lying on thighs

Baseline Final Comments

Appendix 3 – The t-test

The following is a demonstration of the t-test for statistical significance. Shown in the table below is the data taken from Questionnaire 1, back comfort.

Subject	Baseline	Webbing	Difference
1	4	1	3
2	2	1	1
3	3	2	1
4	1	2	-1
6	2	1	1
7	2	1	1
8	3	2	1
9	2	1	1
10	2	1	1
11	3	2	1
12	3	2	1
Mean	**2.45**	**1.45**	**1**

Mean Baseline Rank, $x_{b,m} = 2.45$

Mean Webbing Rank, $x_{w,m} = 1.45$

Mean Difference, $d_{I,m} = 1.0$

Number of Subjects, $n = 11$

1) Calculate the variance:

$$s^2 = \Sigma\,(d_I - d_{I,m})^2 / (n - 1)$$

$$= 2$$

2) Calculate the *t* statistic:

$$t = (x_{b,m} - x_{w,m}) / (s/n^{1/2})$$

$$= 3.71$$

3) Determine significance from *t*-distribution table:

	Level of Significance				
n-1	0.10	0.05	0.025	0.01	0.005
10	1.372	1.812	2.228	2.764	3.169

In this instance, $t>3.169$. Therefore, the level of significance is below 0.0005. It can then be said that the statistical significance can be pronounced with 99.5% confidence.

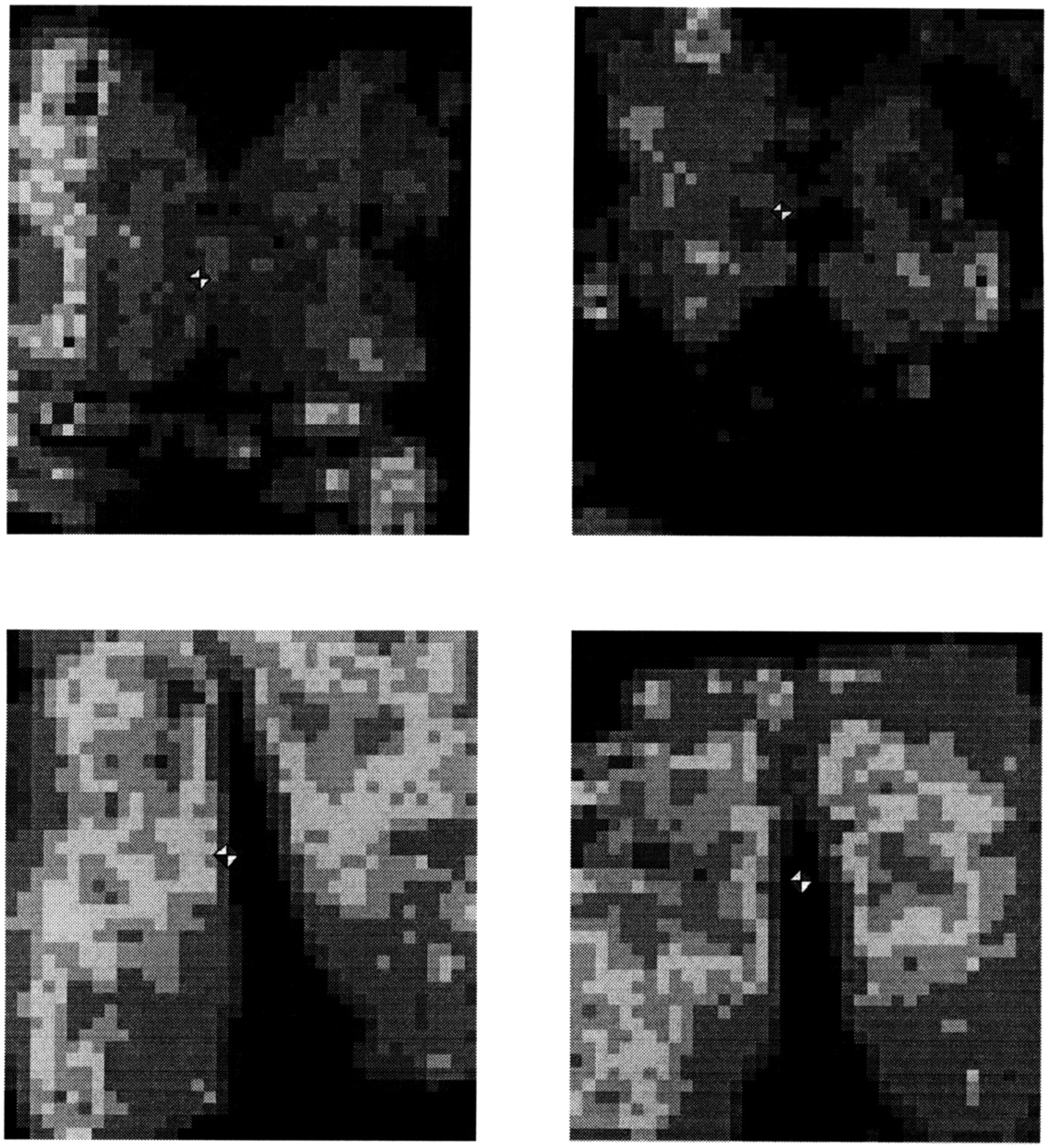
Appendix 4 – Interpretation of Pressure Maps

According to the seat maker Herman Miller, the pressure map of a comfortable seat (i.e. the one on the left) distinguishes itself from one of an uncomfortable seat, pictured on the right, with the following characteristics:

- Peak pressure under sitting bones and lumbar area
- Areas of high pressure away from the spine
- Low pressure in thighs and other areas of the buttocks

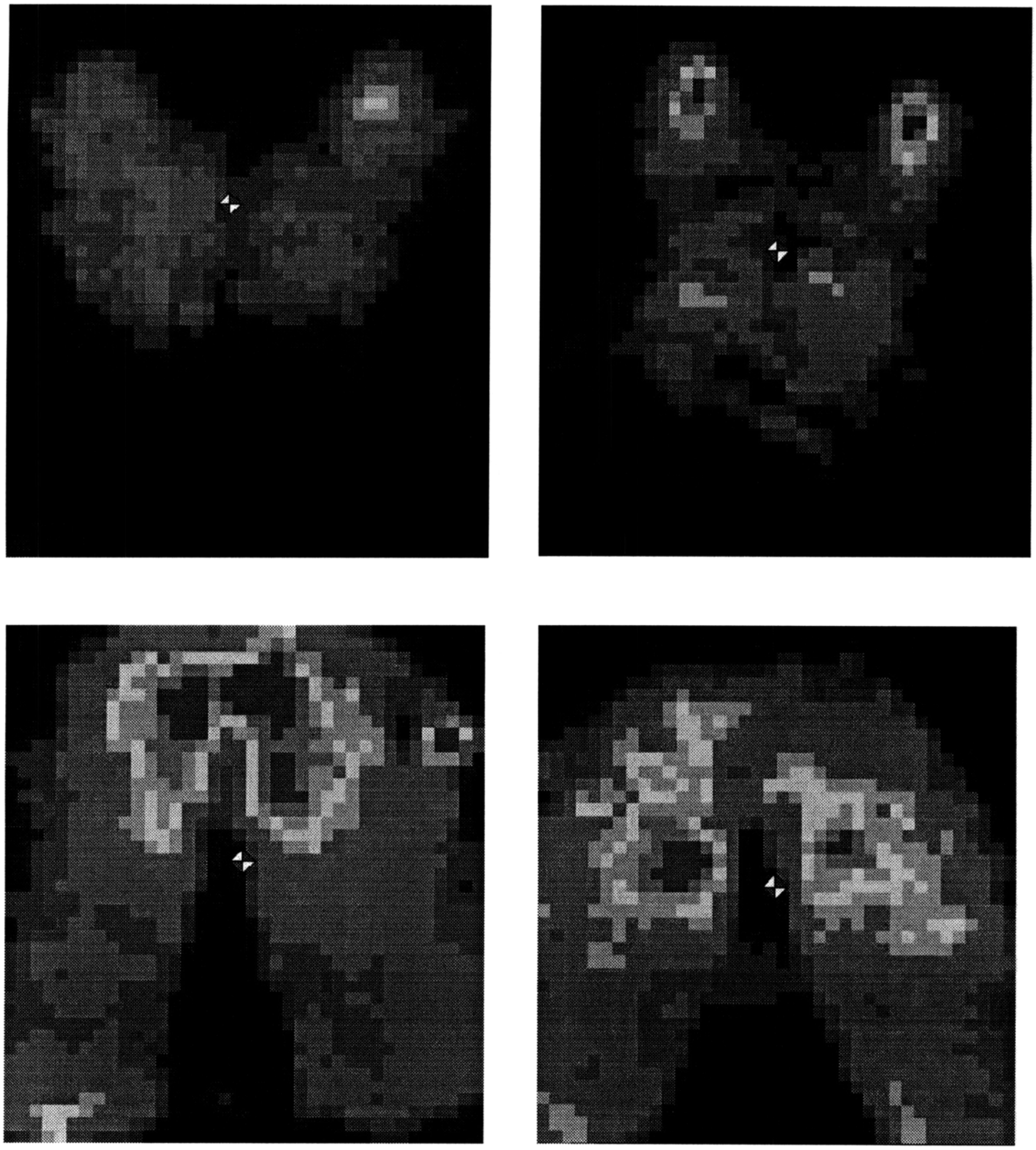
Appendix 5 – Pressure Maps

Subject #1



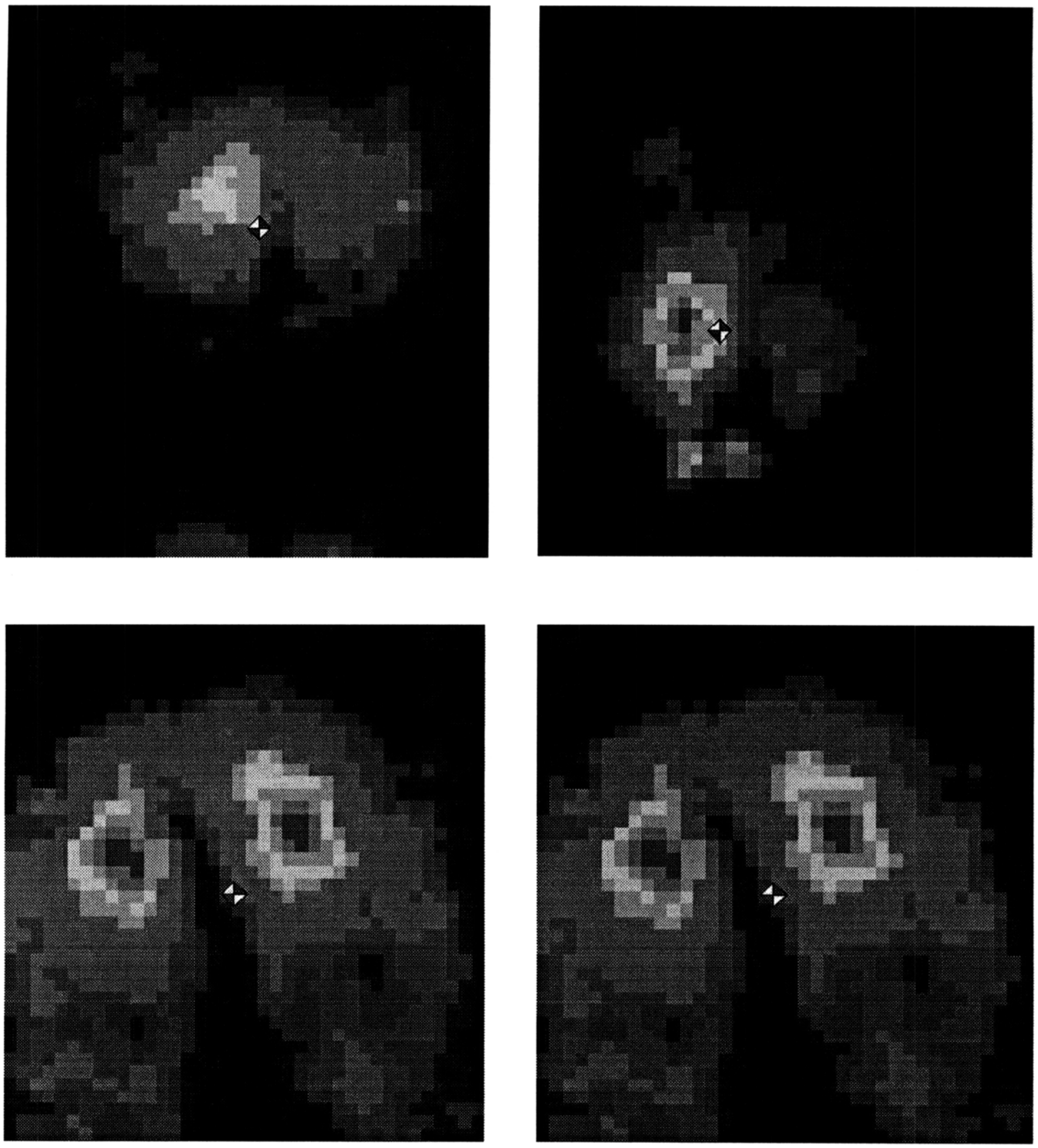
Baseline **Webbing**

Subject #2



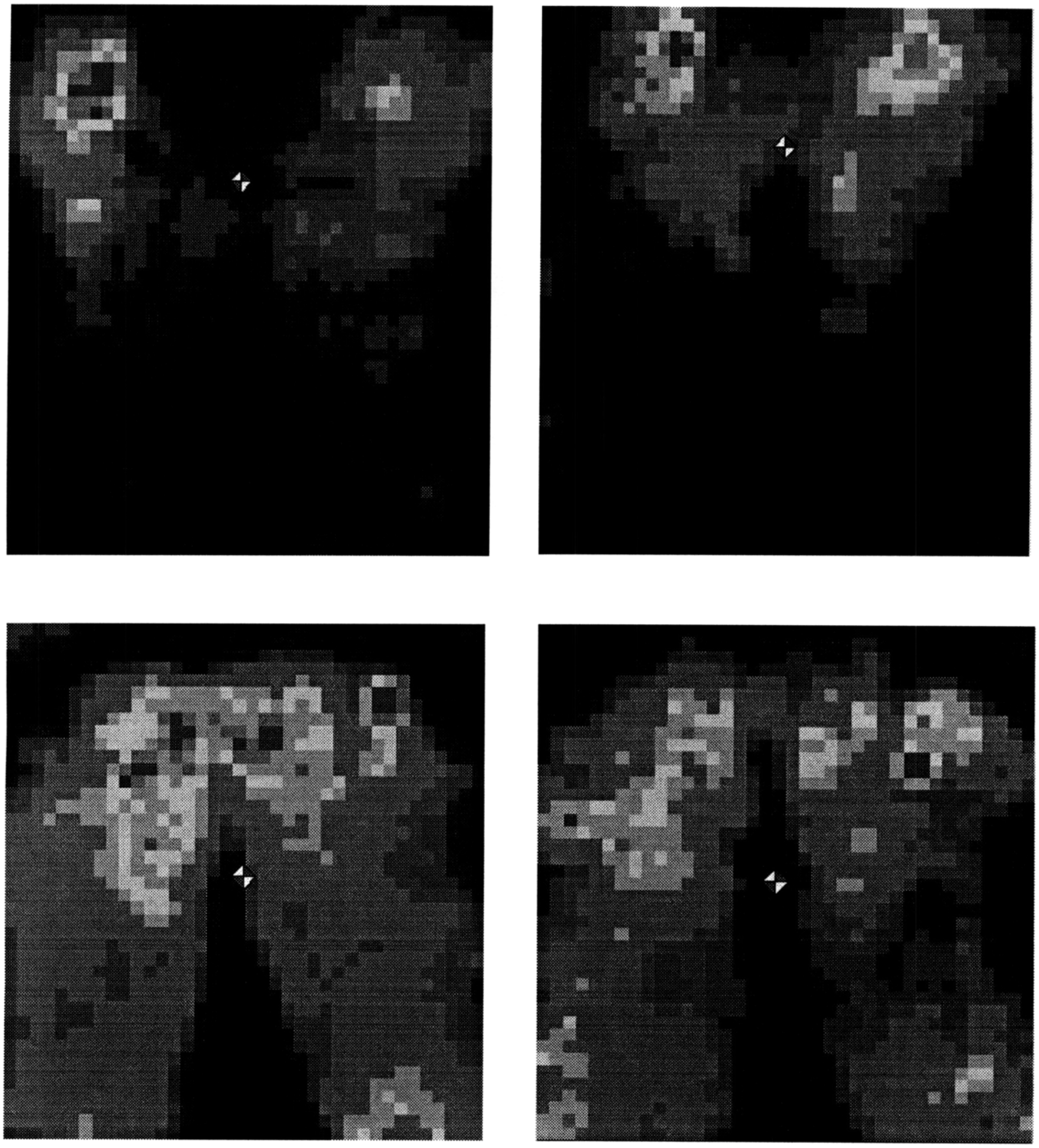
Baseline **Webbing**

Subject #4



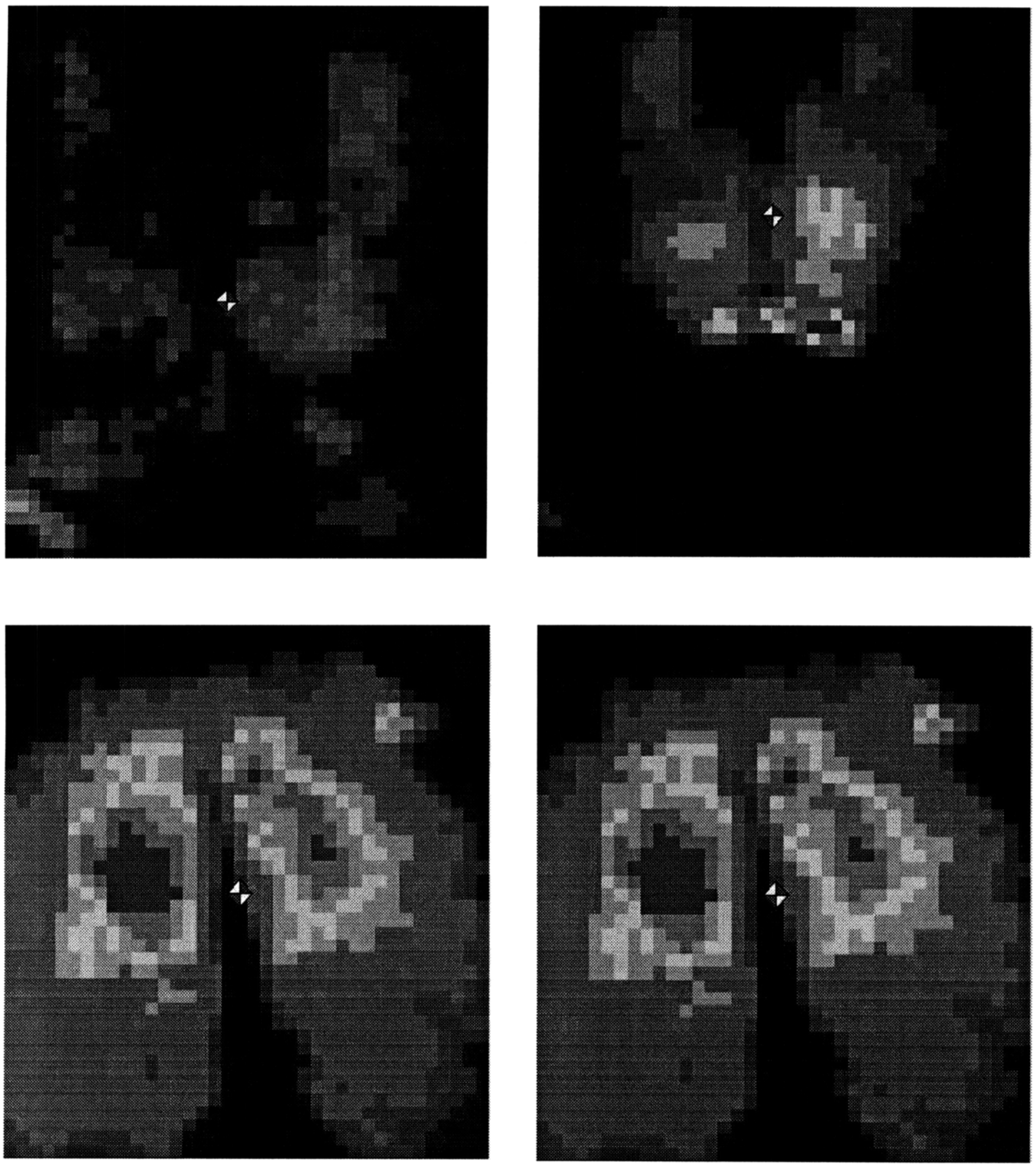
Baseline **Webbing**

Subject #5



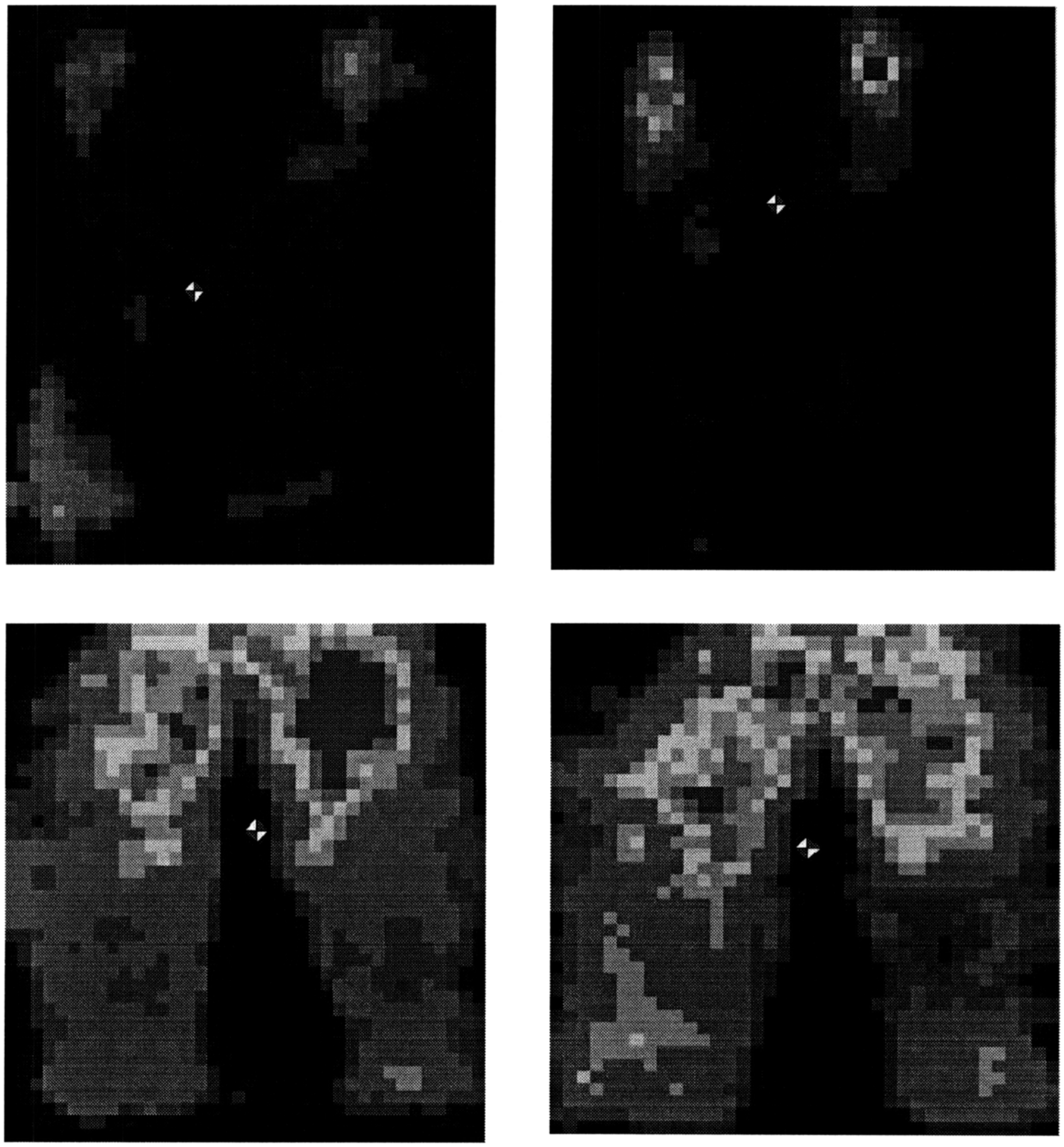
Baseline **Webbing**

Subject #6



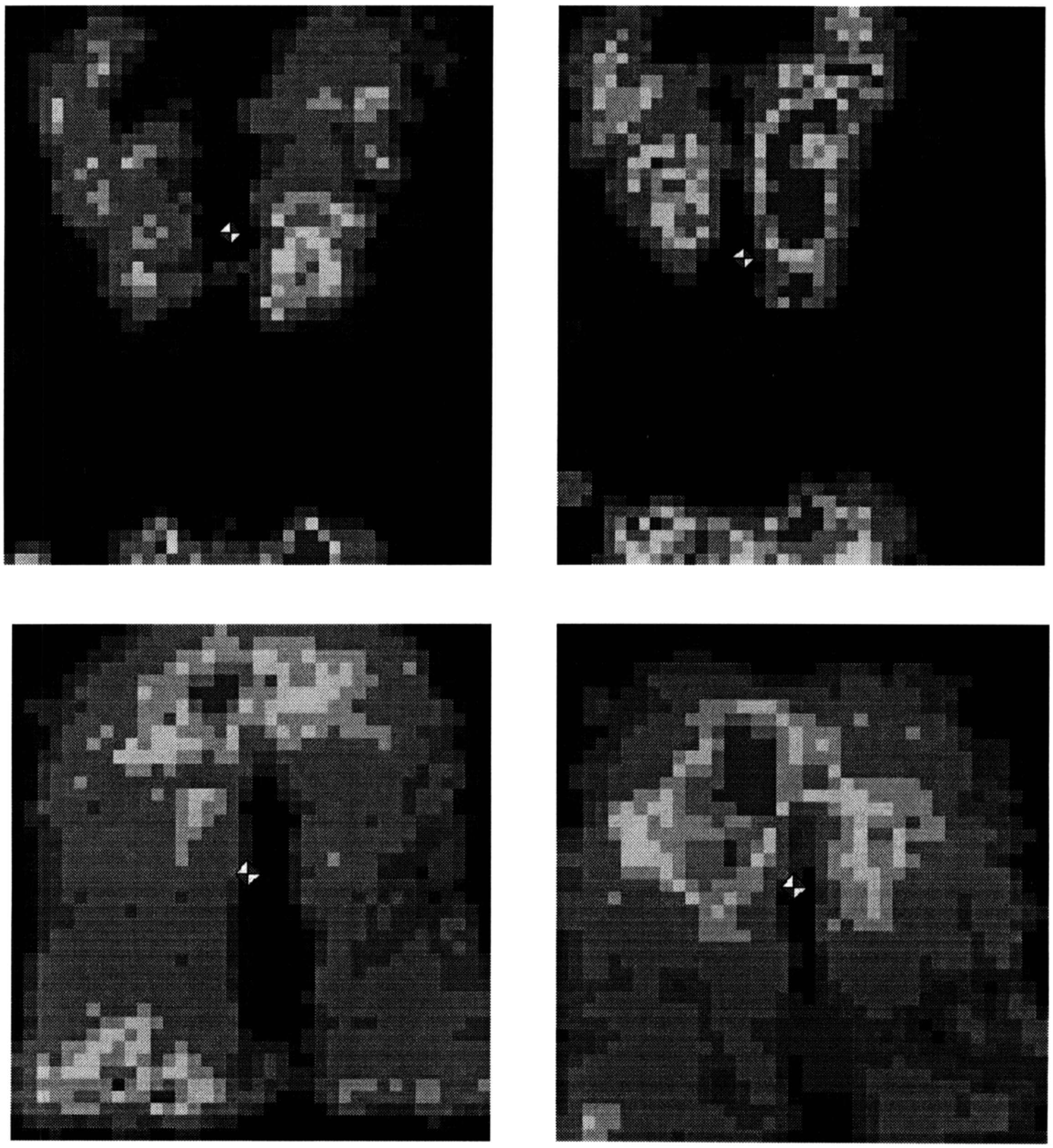
Baseline **Webbing**

Subject #7



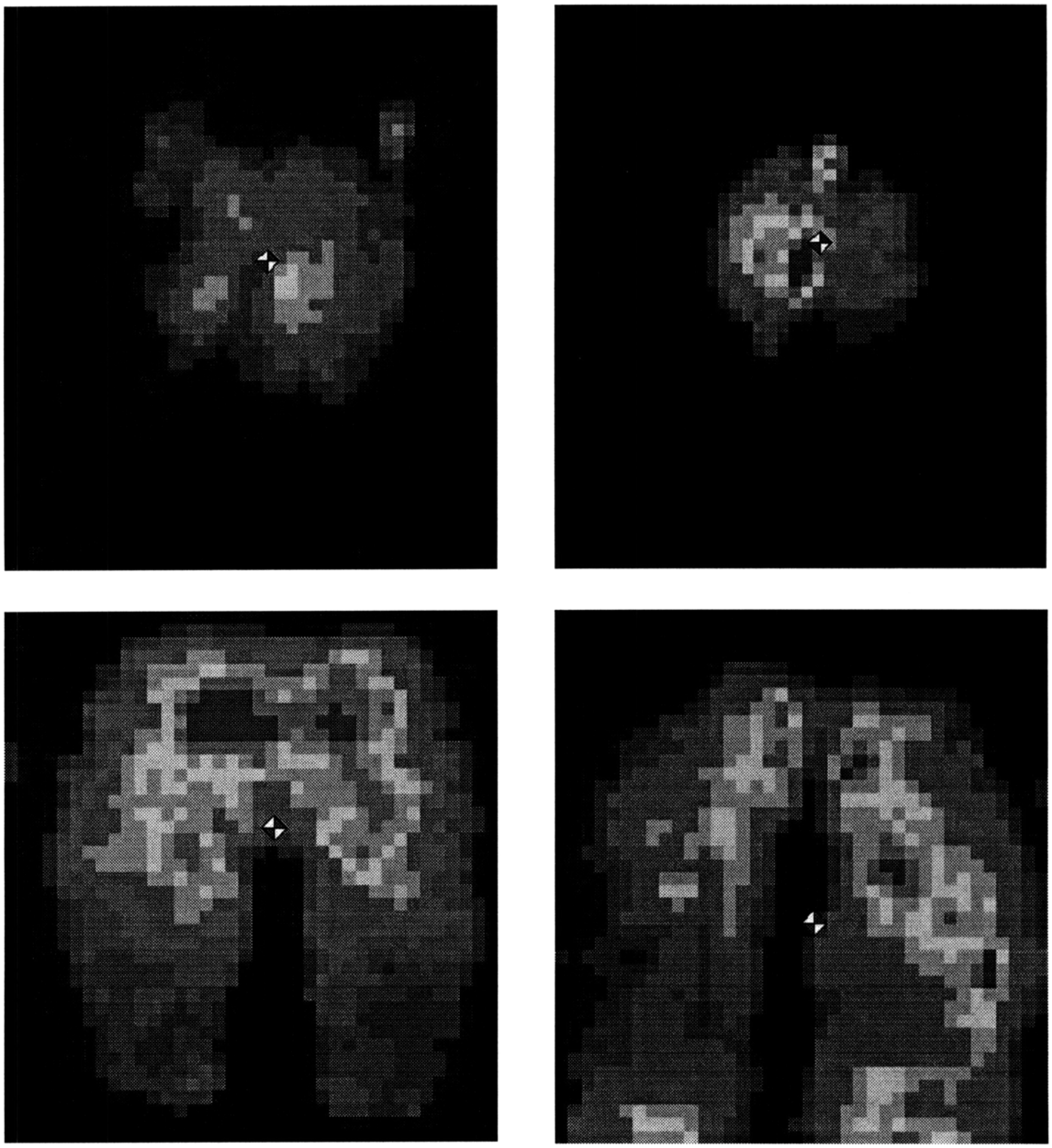
Baseline **Webbing**

Subject #10



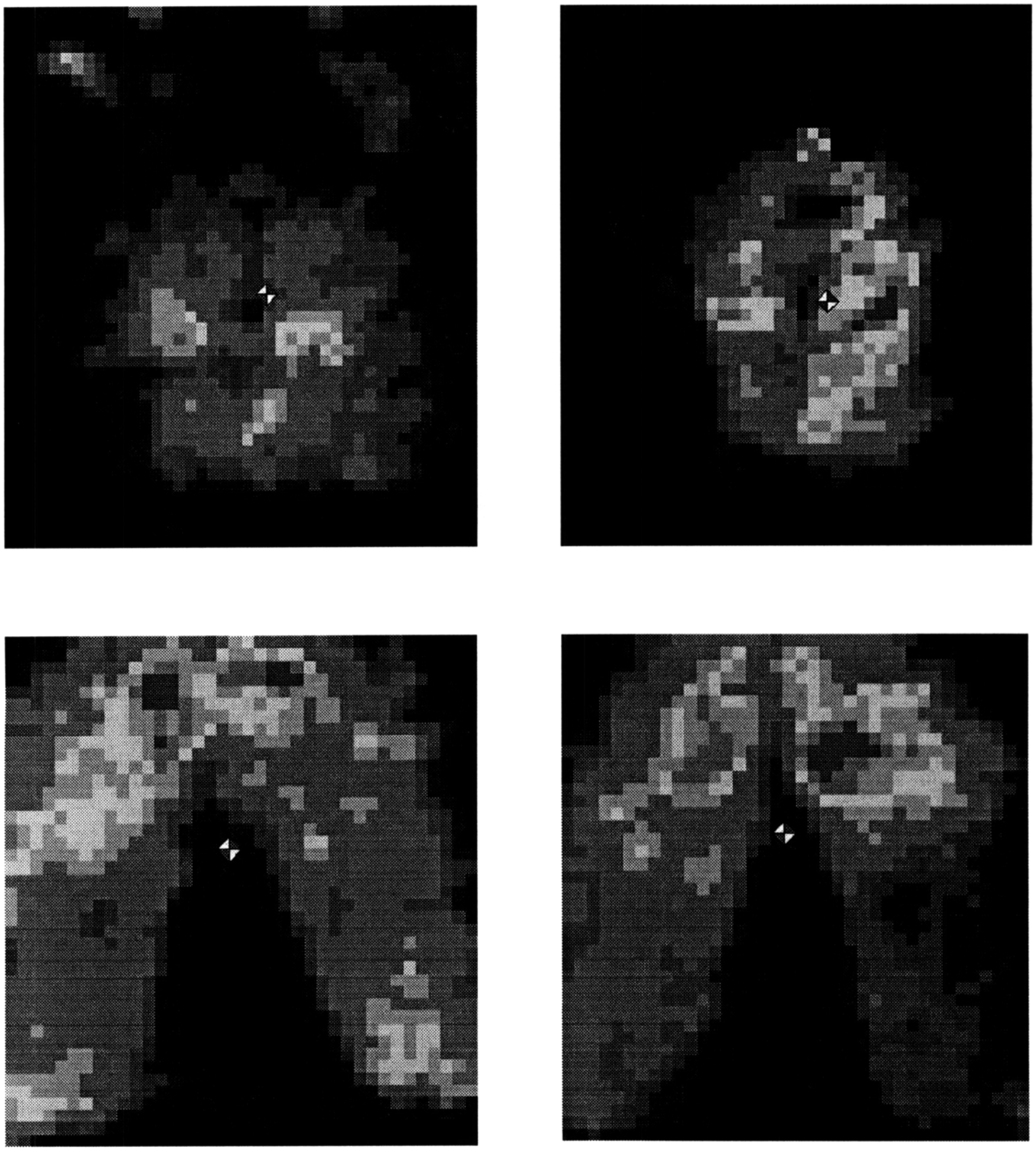
Baseline **Webbing**

Subject #11



Baseline **Webbing**

Subject #12



Baseline **Webbing**

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